Accumulation of trace elements in sediment and biota in the Wouri Estuary, Douala, Cameroon.

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By

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Abstract

The Wouri Estuary on Cameroon's Atlantic Coast is located adjacent to the Douala metropolitan area. Three rivers (Wouri, Dibamba, and Mungo) discharge into the Wouri Estuary. Seventy percent of the industries (soap, brewery, food processing, salt, cement, petroleum and pharmaceutical) in Cameroon are found in the City of Douala. These industries discharge their waste into the estuary. Urban and agricultural runoff are also discharged into the estuary. The urban population of the City of Douala consume shrimp and fish from the estuary daily. This thesis investigated the concentrations of trace element (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) in sediment and biota (bonga, catfish and shrimp) in the Wouri Estuary and assessed the human health risk associated with the consumption of fish and shrimp sourced from the estuary by households in the Douala's Akwa and Makepe Missoke neighbourhoods.

A questionnaire based survey was used to collect data on the consumption rates of fish and shrimp in the Douala's Akwa and Makepe Missoke neighbourhoods. The results of the survey showed that more than 60% of households in both neighbourhoods consumed fish and shrimp sourced from the Wouri Estuary. Average consumption rates ranged from 39-387g for dried shrimp and fish, and 455-2083.3g for fresh shrimp and fish.

None of the sediment samples collected from the Wouri Estuary had trace element concentrations that exceeded the ANZECC Interim Sediment Quality Guideline High. However, concentrations of Cr, Cu and Ni exceeded the ANZECC Interim Sediment Quality Guideline Low at some sites. The trace elements most enriched in sediment from the Wouri Estuary were Cd, Cu and Pb.

The concentrations of As, Cd, Cr, Cu, Pb and Zn were generally higher in liver than in gills and muscle of bonga and catfish. None of the trace element concentrations in biota exceeded guidelines for human health. Although trace element concentrations were low, the risk assessment conducted for the Douala's Akwa and Makepe Missoke neighbourhoods indicated that As and Pb from dried fish bought from the market are of concern for fish consumers.

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Abbreviations

ANOVA	Analysis of variance
ANZECC	Australian and New Zealand Environment and Conservation Council
HNO3	Nitric acid
HCL	Hydrochloric acid
CRM	Certified reference material
ICP-MS	Inductively coupled Plasma-Mass Spectrometry
ISQG	Interim sediment quality guideline
JECFA	Joint FAO/WHO Expert Committee on Food Additives
PTMI	Provisional Tolerable Monthly Intake
PTWI	Provisional Tolerable Weekly Intake
OM	Organic matter

1 Introduction

1.1 Estuaries

Estuaries are an interaction zone between freshwater from land and salt water from the ocean. They provide a diversity of habitats to plants and animals including shellfish, shrimp, fish, lobsters, marine worms, seagrasses, reeds, mangroves, phytoplankton, and algae. Different species of aquatic organisms use estuaries for breeding, feeding, spawning and as nurseries for their young (Elliott & Hemingway, 2002). In addition, estuaries control the exchange of trace elements between rivers and coastal areas (Das, Justic, & Swenson, 2010).

Worldwide, estuaries and river banks are a preferred site for human settlement, industrial development, tourism, recreation, agriculture, and forestry, and as a result estuaries are becoming polluted (Xu et al., 2013). They act as a sink for contaminants released from adjacent catchments and terrestrial areas (Kennish & Fertig, 2012). Globally, estuaries are frequently used as dumping grounds for rubbish, sewage, and industrial waste leading to the pollution of coastal marine areas. Urban and agricultural runoff and ground water can also transport a wide range of contaminants including those sourced from waste discharges and accidental spills to coastal marine areas (Water and Rivers Commission, 1997).

Soil erosion has increased as a result of widespread removal of native forest, agriculture, roadbuilding and urban development (Pimentel, 2006), leading to increased sedimentation in the coastal environment. During rain storms and other precipitation events, water running off impervious surfaces (roads, parking lots and sidewalks) tends to pick up chemicals (e.g. gasoline, motor oil, trace elements, and other pollutants) and carry them to storm drains (Freeborn, Sample, & Fox, 2012). These chemicals attached to fine sediment particles, are transported down streams and rivers and, ultimately get deposited in estuaries. The concentration of trace elements in the sediment represents trace elements that have accumulated over a period of time (Alyazichi, Jones, Mclean, Altalyan, & Al-Nasrawi, 2015).

1.2 Trace elements

Trace elements (also known as microelements) are chemical elements whose concentration in Earth's crust is less than 0.1% by mass (Navratil & Minarik, 2005). They play a vital role to biota but are toxic when concentrations exceed a certain limit. Trace elements (e.g. Cadmium, Lead, Mercury, Copper) that enter aquatic environments are persistent in nature (Jiann & Ho, 2014). They can accumulate in sediments and may also be released to the water column after resuspension (Saulnier & Mucci, 2000). Trace elements are also known to play a dual role in the marine environment, either as essential micro-nutrients (e.g. Fe, Co, Zn, Cd, Cu)(Morel & Milligan, 2003) or as toxic agents especially when present in high concentrations(e.g. Cu, Pb, Cd, Ni, Cr, Hg, As). Trace elements may pose a risk to animals higher in the food chain through the processes of bioaccumulation and trophic transfer (Stankovic & Jovic, 2012).

In estuarine and coastal waters trace element concentrations are usually higher than in open oceanic waters (Bruland & Lohan, 2003). The high concentration or accumulation of trace elements in these water bodies is attributed to both anthropogenic and natural inputs. The natural sources include surface runoff, groundwater discharges, transport of weathered crust material via rivers, atmospheric deposition and diffusion from sediments (Moore, 1996). The dominant anthropogenic sources of trace elements to aquatic systems include discharges from industrial facilities and effluent (Beck, Cochran, & Sañudo-Wilhelmy, 2009).

Fish can accumulate trace elements in their tissues, and can be used as excellent biological markers of elements in aquatic ecosystems (Benson, Essien, Williams, & Bassey, 2007). Trace elements differ in their accumulation levels and patterns depending on fish tissue, as well as fish species (Visnjic-Jeftic et al., 2010). The primary site of trace element uptake from water are the gills, especially if the trace elements are bound to particulate matter (Klavins, Potapovics, & Rodinov, 2009) , while the liver which is a metabolically active tissue due to the presence of metal-binding proteins is also an accumulation site for elements (Ploetz, Fitts, & Rice, 2007). When a toxic metal (e.g. mercury) is deposited in surface water, it can enter a fish's bloodstream via water passing over the gills and accumulate in the muscle tissue

(Shimshack, Ward, & Beatty, 2007). Muscles are therefore important tissue in trace elements accumulation. Since they are not the only indicators of chemical substances present in fish, the analysis of other tissues such as gills and liver are important as well.

Shrimp and fish are important protein sources that supply essential trace elements and nutrients for humans. However when contaminated, they represent a potential risk for predatory birds, fish and mammals that feed on them (Jezierska & Witeska, 2006). Trace elements are present in seafood in different concentrations. Seafood is an important exposure pathway to trace elements for humans. People consuming large amounts of contaminated seafood may have elevated concentrations of trace elements in their tissues. These elevated trace elements intakes may pose a significant health risks to their system. The health effects of consuming seafood with elevated trace elements include severe nervous system problems in young children and kidney failure in adults (Hellberg, Mireles DeWitt, & Morrissey, 2012). In addition, trace elements can cause neurotoxic and carcinogenic effects in vital organs in the human body such as the bones and liver (Duruibe, Ogwuegbu, & Egwurugwu, 2007).

Legislation has been implemented worldwide related to monitoring, assessing, and managing ecological integrity to protect the aquatic environment and provide safe, clean, healthy and productive habitats (Borja et al., 2008). For example the European Water Framework Directive (WFD) and the Marine Strategy Framework Directive (MSFD) in Europe have implemented legislation to achieve good ecological status in all European water bodies by 2015 and good environmental status in offshore waters by 2020. In Africa, the National Water Act in South Africa was implemented to regulate water quality issues, e.g. pollution prevention and the use of water. The Federal Environmental Protection Agency (FEPA) was established by the Federal Government of Nigeria to limit effluent and industrial emission, pollution reduction in industries, management of solid and hazardous wastes (UNEP, 2014). In Cameroon, Law No 96/12 was implemented by the Ministry of Environment and Protection of Nature to protect the coast and marine waters of Cameroon from harmful or dangerous substances (MINEP, 2000).

1.3 Wouri Estuary

The Wouri Estuary, located in the Douala Basin, is a large tidal estuary on Cameroon's Atlantic coast. The estuary is a global marine biodiversity hotspot and contains wetlands of international importance (FAO, 1987). The estuary extends along a coastline of 60km and covers a surface area of 1800km^2 (Gabche & Smith, 2002). The mangrove forests and mudflats in the estuary are breeding grounds for fish, shrimp, and home to many waterbirds (such as African grey parrot, pelican, owl, fish eagle and the kingfisher) and other wildlife (giant crocodile, African python, blue monkey, bush pig, African manatee and mangrove antelope). Two large urbanized rivers (Wouri and Dibamba) and one smaller river (Mungo) flow through agricultural land, discharge into the estuary (Figure 1.1). The communities within and around the estuary depend on fishing for their livelihood and survival. The estuary is located adjacent to the Douala metropolitan area and is, consequently, subject to agricultural, industrial, and other anthropogenic effluents.

Seventy percent of the industries (soap, brewery, food processing, salt, cement, petroleum and pharmaceutical) in Cameroon are found in the city of Douala (Asangwe, 2006). These industries discharge their waste into the coastal environment resulting in pollution in the Wouri Estuary (Asangwa, 2006). Several point and non-point pollution sources are present in the greater area of the Wouri Estuary. The point sources discharging into the Wouri River include industrial discharge and untreated effluent, whereas those discharging into the Dibamba River come from the Bassa industrial zone and include numerous polluting activities such as food industries, iron works, breweries, soap industries and military installations (Asaah, Abimbola, & Suh, 2006). The non-point pollution sources for the Wouri Estuary include atmospheric deposition of metals, agricultural runoff, oil, grease and toxic chemicals from urban runoff and energy production (Ngoran & XiongZhi, 2014).

Figure 1. 1: Greater area of the Wouri Estuary.
(Source: google map)

1.4 The City of Douala

Douala is the capital of Cameroon's Littoral Region and the largest city in Cameroon. Home to Central Africa's largest port, it is the economic and commercial capital. As of 2010, the population of the city and its surrounding area was estimated at over 2 million inhabitants (Mbarga, 2010). A large percentage of the population live below the poverty line even though the city is the economic centre of Cameroon (Robert, 2014). The city is adjacent to the Wouri Estuary and covers an area of between 200-210km^2. In addition, Douala is a cosmopolitan city with people from different parts of the country and the world. The Douala metropolis comprises of six divisions (Douala 1, Douala 2, Douala 3, Douala 4, Douala 5, and Douala 6) with more than 120 neighbourhoods (Moses, 2016). Different forms of human activities ranging from primary, secondary and tertiary industries operate in these neighbourhoods.

The city's rapid growth in recent decades has caused environmental effects in the surrounding lagoons complex and the wetlands. The wetland ecosystem of tidal mud flats, mangroves, wetlands, estuaries, and inlets where creeks flow into lagoons, all of which provide habitats for aquatic organisms, has been destroyed by the rapid expansion of the Douala metropolitan areas (Moses, 2016). Wetlands have been converted for industrial infrastructure and development, as well as land reclamation for urban growth, accompanied by an increase in the discharge of industrial waste and effluents (Chebo, 2009). This expansion/growth has resulted in the contamination of surface and ground water sources (Chebo, 2009).

Fish and shrimp are consumed in every region of Cameroon. As a source of nutrition, they play an important role in food security and are also a very rich source of animal protein in the diet of both rural and urban households (Achu, 2009). The availability of the different species of fishery products in the market has given rise to a strong tradition of fish eating in most regions of the country. The demand for these products is increasing and the country relies on imported fish to meet the demands of the population. However, the importation of fish and other fishery products into Cameroon, of approximately 100,000 tons each year, does not meet the national demand (Pouomogne & Pemsl, 2008). As a result, the country depends on fish and shrimp sourced from coastal environments, inland water bodies, aquaculture and estuaries to meet these demands.

The main species of fish and shrimp sourced from these water bodies include Tiger crayfish *(Penacus kerathusus),* Bonga *(Ethmalosa fimbriata)*, Catfish *(Arius heudelotii Valenciennes 1840 & Siluriforms*), Estuarine white shrimp or njanga *(Palaemon),* Bobo croaker or nyendi *(Pseudotolithus elongates),* Threadfin *(Galoides),* Shad or munyanya *(Ilisha africana),* and Tilapia *(Oreochromis niloticus)*(FAO, 1983). Although these water bodies produce many different fish and shrimp species, *Penacus kerathusus, Ethmalosa fimbriata, Arius heudelotii Valenciennes 1840* and *Palaemon* from the Wouri Estuary are the most valuable species consumed by the population of Douala and other regions of Cameroon.

1.5 Thesis aim, objectives and layout

Very little research has undertaken to determine the concentrations of trace element in sediment and biota in the Wouri Estuary. Due to the fact that the urban population of the city of Douala eat shrimp and fish from the estuary daily, a human health risk assessment is necessary. With the numerous industrial, agricultural, and residential areas along the Wouri, Dibamba and Mungo River, the extent of exposure of estuarine biota to potentially toxic trace elements is unknown. Limited studies have been carried out to determine consumption rate for fish and shrimp sourced from the Wouri Estuary in the Douala's Akwa and Makepe Missoke neighbourhood. Therefore, for human health risk assessment purposes, a questionnaire based survey was used to determine the consumption of shrimp, bonga and catfish by the population in these areas.

The aims of this research were to determine the concentration of trace elements in sediments and biota in the Wouri Estuary and to assess the human health risk associated with the consumption of shrimp and fish sourced from the estuary. The objectives of this study were:

(a) To determine spatial variability in sediment trace element concentrations in the Wouri Estuary, Cameroon

(b) To determine concentrations of trace elements in shrimp and fish (bonga-*Ethmalosa fimbriata*/catfish) in the Wouri Estuary

(c) Undertake a health risk assessment for the consumption of shrimp and fish sourced from the Wouri Estuary and

(d) To determine the effect of sample pre-treatment on trace element concentrations in biota.

A detailed study of the consumption rate of shrimp and fish in the Douala's Akwa and Makepe Missoke neighbourhoods is presented in Chapter 2. Chapter 3 presents the methods used in this study. The results of trace elements analysis in sediments and biota collected from the Wouri Estuary are presented in Chapter 4. The health risk associated with the consumption of shrimp and fish sourced from the Wouri Estuary was assessed using WHO/JECFA PTWI values and Nutrient Reference values for Australia and New Zealand is also presented in Chapter 4. Recommendations for future research, limitation of the study and conclusions are also included in this thesis in Chapter 5.

2 Fish consumption in the Douala's Akwa and Makepe Missoke Neighbourhood.

2.1 Introduction

Fish is an important animal source of food for a healthy diet not only for its protein and essential fatty acid contents, but also for many other micronutrients and minerals (Feng, Jian, WeiSong, ZeTian, & XiaoShuan, 2009). Modest consumption of fish, reduces risk of coronary death by 36% (Mozaffarian & Rimm, 2006). In addition, eating shrimp and fish reduces the risk of cardiac death and improves neurodevelopment in infants and young children (FAO & WHO, 2010). Globally, fish consumption on a per capita basis has increased over recent decades (Kearney, 2010). The increasing world population, rising incomes, higher living standards, economic development and increasing urbanisation are the driving forces behind the enormous surge in the consumption of fish products (FAO, 2014). Different eating habits, traditions, prices and socio-economic levels have also resulted in large variations in the amount of fish consumed across countries and regions of the world. Consumption also differs within countries and among segments of society. These differences are a result of consumer preferences, frequency of consumption, amount consumed, availability, accessibility, family size, prices and levels of disposable income (Trondsen, Braaten, Lund, & Eggen, 2004).

Interviews and surveys are the most common ways data on fish consumption can be gathered. Both are different data collection methods, irrespective of the fact that they involve asking people questions. Information collected using these methods are self-reported data or data collected in an indirect manner. Interviews can be carried out in person or by phone and respondents questioned on a particular subject. In addition, interviews can be open-ended involving a panel or representative stakeholders who are routinely interviewed over a period of time, or involve focus groups (5-15 representatives individuals) using initial questions (Halls et al., 2005). Surveys are also a popular method used for collecting data on fish consumption. They can be carried out in person or via email by asking respondents about their opinions and behaviours using a short questionnaire. Another way data on fish consumption can be gathered is to have literate people fill in a questionnaire. For example, respondents may be given a questionnaire on which they are asked to record what they eat. This method can provide useful information about consumption patterns, frequency of consumption, seasonal variations in consumption and the quantity consumed (Zhao, Hasegawa, & Chen, 2002)

Fish is consumed in all the neighbourhoods, villages and cities in Cameroon. It plays an important role as a source of protein and food for millions of Cameroonians. Reported consumption rates per person range from 30kg- 48kg per year as of 1961 (Belhabib & Pauly, 2015). Total consumption increased between 1980 and 1998 by more than 24,000 metric tonnes (Tambi, 2001) with urbanisation and income growth, the major driving forces behind these increases. A decline in the consumption of fish and shrimp in Cameroon was recorded in 2010 with an average person consuming 11.7kg of fish per year (Belhabib & Pauly, 2015). Since 2010, very little is known about the consumption rate for fish and shrimp in Cameroon including the city of Douala's Akwa and Makepe Missoke Neighbourhoods. Therefore a questionnaire based survey was used to determine the consumption rate of shrimp and fish in the Douala's Akwa and Makepe Missoke neighbourhood.

2.2 Objectives

The objective of this study was to obtain data on the consumption rates of bonga, catfish and shrimp by households in Douala's Akwa and Makepe Missoke neighbourhoods. This data will be used in the risk assessment for fish and shrimp consumption in Chapter 4.

2.3 Survey locations

Households from two neighbourhoods in Douala were interviewed for the survey (Table 2.3 and Figure 2.1). The Akwa neighbourhood was selected because the Sawa (the indigenous people of Douala) are the most prominently represented ethnicity in the neighbourhood and seafood is an integral part of their cultural heritage. As a result, they were the most targeted ethnicity in this neighbourhood though other people from different ethnic backgrounds were also interviewed. The Makepe Missoke neighbourhood was selected because of its cultural diversity. Most households from this neighbourhood came from different regions in Cameroon.

Figure 2. 1: Locations of the neighbourhoods interviewed in Douala

2.4 Methodology

The rapid participatory appraisal method was used to collect information about shrimp and fish consumption from households. Face-to-face interviews for this survey were carried out with households in the Akwa and Makepe Missoke neighbourhood using the questionnaire in Appendix 1. This was done by going door to door and interviewing participants in the selected neighbourhoods. Participants were provided with two options to answer questions (open-ended and closed-ended). They selected their answer from the range of responses provided. They were asked to make a defined choice (e.g. YES/NO). Respondents also provided consumption information for children residing in their households.

The amount of shrimp (g) and fish consumed by respondents was calculated based on data collected during the survey. The majority of respondents buy shrimp and locally dried fish from the market without knowing the weight. The cost of the shrimp and fish was used to calculate the weight purchased (Table 2.1).

Table 2. 1: Cost and weight of shrimp and fish based on data from the survey.

Shrimp				Bonga				Catfish			
Locally dried		Fresh		Locally dried		Fresh		Locally dried		Fresh	
Weight (g)	Cost in francs	Weight (g)	Cost in francs	Weight (g)	Cost in francs	Weight (g)	Cost in francs	Weight (g)	Cost in francs	Weight (g)	Cost in francs
14	100	60	200	54	200	1250	1000	175	750	750	1500
28	200	150	500	59	300	1500	1500	196	1000	1000	2000
42	300	300	1000	114	500	1750	2000	250	1500	1250	2500
52	500	600	2000	256	1000	2000	3000	-	-	2500	5000
67	600	780	2600	370	1500	-	-	-	-	-	-
154	1500	900	3000	-	-	-	-	-	-	-	-
206	2000	1200	4000	-	-	-	-	-	-	-	-
-	-	1500	5000	-	-	-	-	-	-	-	-

2.4.1 Questionnaire design

The questionnaire was designed to ensure that valid responses were obtained from the survey. It was based on previous consumer surveys carried out in Mauritius and other countries (FAO, 2013). The questionnaire included both open-ended and closed questions. The open-ended questions allowed the participants to express themselves freely while the closed ended questions consisted of likert scale questions to assess the attitudes of participants. The two page survey questionnaire (Appendix 1) included 17 questions and was approved by the Human Ethics Committee at the University of Canterbury. These questions were divided into four major sections as shown in Table 2.2.

Table 2. 2: Four sections in the questionnaire

Section A Consumption	This section consisted of questions on whether households eat fish and shrimp. It also consisted of questions on the amount of shrimp and fish consumed and the frequency of consumption. Households were asked to identify the parts of bonga and catfish consumed.
Section B: Preparation methods	This section consisted of general questions on the methods of preparation. Households were asked about the methods used to cook shrimp, bonga and catfish.
Section C: Reasons for eating fish and shrimp	This section consisted of questions about why households eat fish and shrimp.
Section D: Importance of fish and shrimp to consumers	Participants were asked to rate different statements using a four-point likert scale ranging from not important, somewhat important, important and very important.

2.4.2 Interview process

The interviews were conducted in the Douala's Akwa and Makepe Missoke neighbourhood between July and August 2016. Fifty households were randomly selected to be interviewed in the Douala's Akwa and Makepe Missoke neighbourhood. Twenty-five households per neighbourhood were interviewed with the use of a questionnaire. One participant from each household was involved in the survey. Participants were briefed about the purpose of the survey before they were interviewed. The interview process for each participant lasted for approximately 20-25 minutes and all the questions were asked in French. The questions were asked in an unbiased manner to encourage the participants to voice their opinions. All participants interviewed were women above 18 years who cooked for the household and were competent to give consent on their own behalf. Participants did not reveal their identity, such as names and house numbers, during the interview process. Due to the confidential nature of the work, all questionnaires were coded to conceal the identity of the respondents.

Table 2. 3: Selected neighbourhoods for the survey and number of households interviewed in Douala.

No	Neighbourhood	No. of households interviewed	Administrative location	Dates surveyed
1	Akwa	25	Douala 1	July 2016
2	Makepe Missoke	25	Douala 5	August 2016

2.4.3 Data analysis

The data collected from the survey was analysed using Microsoft Excel 2013. The consumption rates for bonga, catfish and shrimp were calculated by dividing the households that ate bonga, catfish and shrimp by the total number of households interviewed (25 households per neighbourhood).

2.5 Results

2.5.1 Consumption rates for bonga, catfish and shrimp

Number of households who responded with 'Yes' or 'No' to the consumption of bonga, catfish and shrimp.

Table 2. 4: Number of households consuming bonga, catfish and shrimp

	Makepe Missoke			**Akwa**		
Responds	Shrimp	Bonga	Catfish	Shrimp	Bonga	Catfish
Yes	22	24	16	23	16	15
No	3	1	9	2	9	10

2.5.2 Consumption rates for shrimp

Consumption rates for shrimp were similar between the two neighbourhoods. There was a slight increase in shrimp consumption in the Akwa neighbourhood compared to the Makepe Missoke neighbourhood (Figure 2.2).

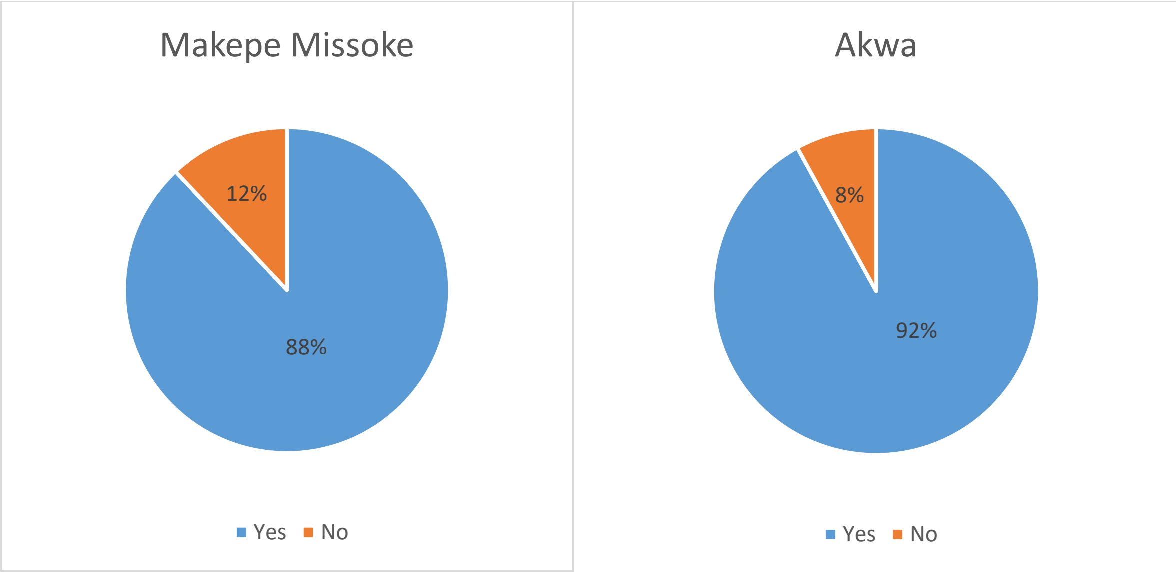


Figure 2. 2: Consumption rates for shrimp

2.5.3 Consumption rates for bonga

Bonga consumption was much higher in the Makepe Missoke neighbourhood than in the Akwa neighbourhood (Figure 2.3).

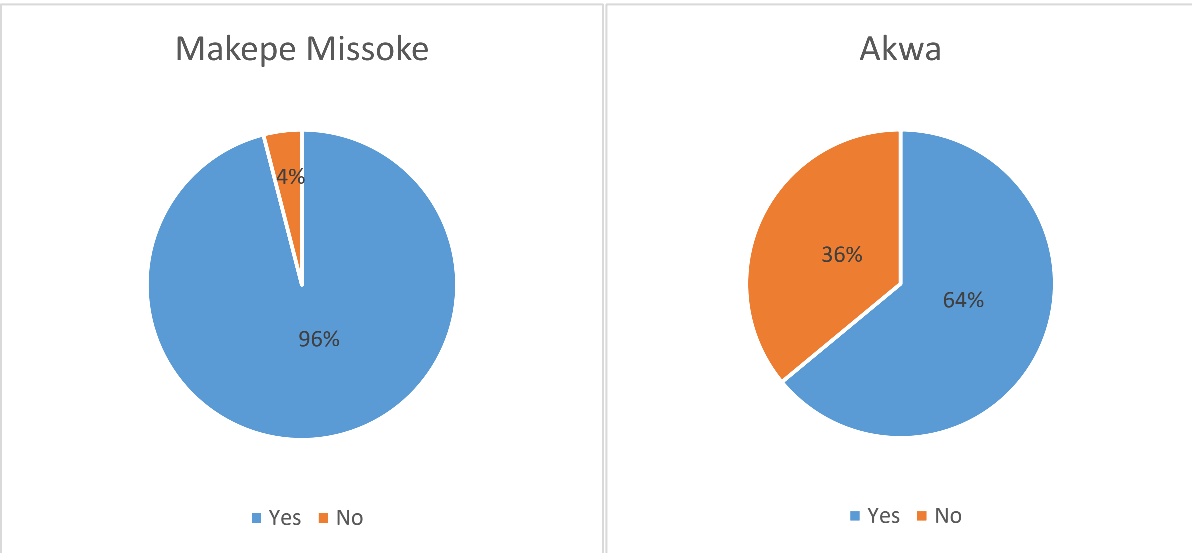
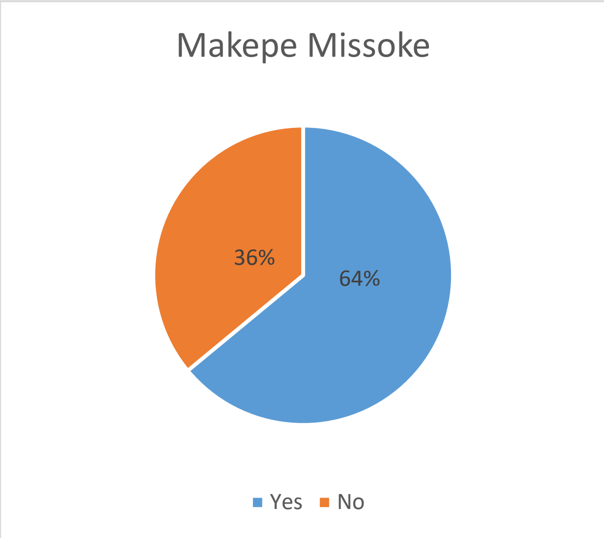


Figure 2. 3: Consumption rates for bonga

2.5.4 Consumption rates for catfish

Consumption rates for catfish were similar between the two neighbourhoods (Figure 2.4).



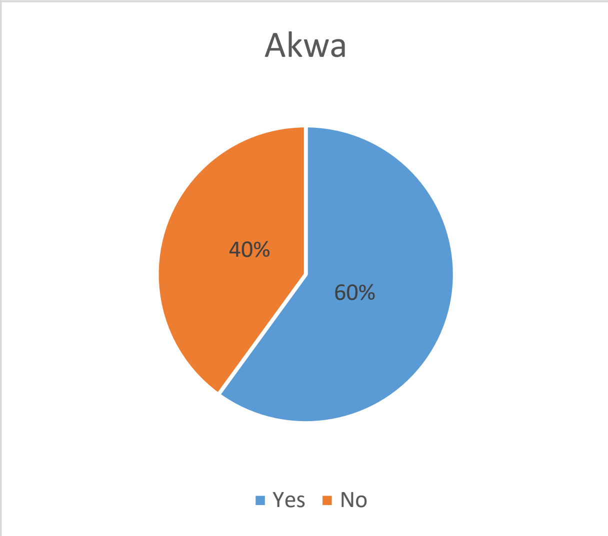


Figure 2. 4: Consumption rates for catfish

2.5.5 Frequency of fish consumption (bonga, catfish and shrimp)

In the Makepe Missoke neighbourhood most people ate shrimp weekly whereas in the Akwa neighbourhood, shrimp was most frequently consumed monthly. Most people ate bonga weekly in the Makepe Missoke neighbourhood while in the Akwa neighbourhood most bonga was frequently consumed monthly. Catfish was frequently consumed monthly between the two neighbourhoods. However, the frequency of eating catfish was higher in the Makepe Missoke neighbourhood than in the Akwa neighbourhood.

Table 2. 5: Frequency of shrimp consumption in Akwa and Makepe Missoke neighbourhoods

	Makepe Missoke			**Akwa**		
Frequency	Shrimp %	Bonga %	Catfish %	Shrimp %	Bonga %	Catfish%
Daily	4.5	4.2	-	4.3	-	-
Weekly	68.2	66.7	12.5	34.8	33.3	40
Monthly	27.3	29.1	87.5	60.9	68.7	60

2.5.6 Estimated amount of locally dried bonga, catfish and shrimp consumed per person (g) per week in the Akwa and Makepe Missoke Neighbourhood

Average consumption rates of locally dried catfish per person were similar between the two neighbourhoods. However, average consumption rates of locally dried shrimp and bonga in the Akwa neighbourhood were much higher than in the Makepe Missoke neighbourhood.

Table 2. 6: Estimated amount of locally dried bonga, catfish and shrimp consumed (g) per person per week in Akwa and Makepe Missoke neighbourhoods.

	Makepe Missoke			**Akwa**		
	Shrimp(g)	Bonga(g)	Catfish(g)	Shrimp(g)	Bonga(g)	Catfish(g)
Minimum	2	8	33	7.5	32	117
Maximum	652	2100	3100	750	1167	1138
Mean	39	29	387	95.4	240	381
95^{th} Percentile	57	85.3	400	217.3	620	750

2.5.7 Estimated amount of fresh bonga, catfish, gill and shrimp consumed per person (g) per week in the Akwa and Makepe Missoke Neighbourhood

Average consumption rates of fresh catfish in the Akwa neighbourhood were much higher than in the Makepe Missoke neighbourhood. Households in the Makepe Missoke neighbourhood did not consume fresh shrimp and bonga.

Table 2. 7: Estimated amount of fresh bonga, catfish, gill and shrimp consumed (g) per person per week in Akwa and Makepe Missoke neighbourhoods.

	Makepe Missoke		**Akwa**			
	Catfish (g)	Gill (g) Catfish	Shrimp (g)	Bonga (g)	Gill (g) Bonga	Catfish (g)
Minimum	195	5.2	60	1500	10.2	500
Maximum	2500	23	1500	3000	23	7500
Mean	1113	11.4	455	2083.3	14	1813
95^{th} Percentile	1500	14	1200	2250	16.3	3000

2.5.8 Average consumption of bonga, catfish, shrimp per week and per year (g) by households in the Makepe Missoke and Akwa Neighbourhoods

The per capita and average consumption per week of shrimp, bonga and catfish was higher in the Akwa neighbourhood than in the Makepe Missoke neighbourhood. It was apparent that cost (price) was a dominant factor influencing the consumption of shrimp and fish in these neighbourhoods. More than 70% of households mentioned that fish and shrimp were very expensive to purchase in the market.

Table 2. 8: Average consumption of bonga, catfish, shrimp per week and per year (g) by households in the Makepe Missoke and Akwa neighbourhoods.

	Makepe Missoke (Shrimp, Bonga and Catfish)		**Akwa (Shrimp, Bonga and Catfish)**	
	Consumption per week (g)	Consumption per year (g)	Consumption per week (g)	Consumption per year (g)
Minimum	35.5	672	50.5	2,424
Maximum	3,064	147,072	5,069	243,312
Mean	101.4	4,900	223.4	10,700

2.5.9 Preferred parts consumed for bonga in the Akwa and Makepe Missoke Neighbourhood

The majority of people consumed the whole fish in the Makepe Missoke neighbourhood whereas most people in the Akwa neighbourhood consumed the muscle only. A small percentage of people consumed the gills in both neighbourhoods (Figure 2.5).

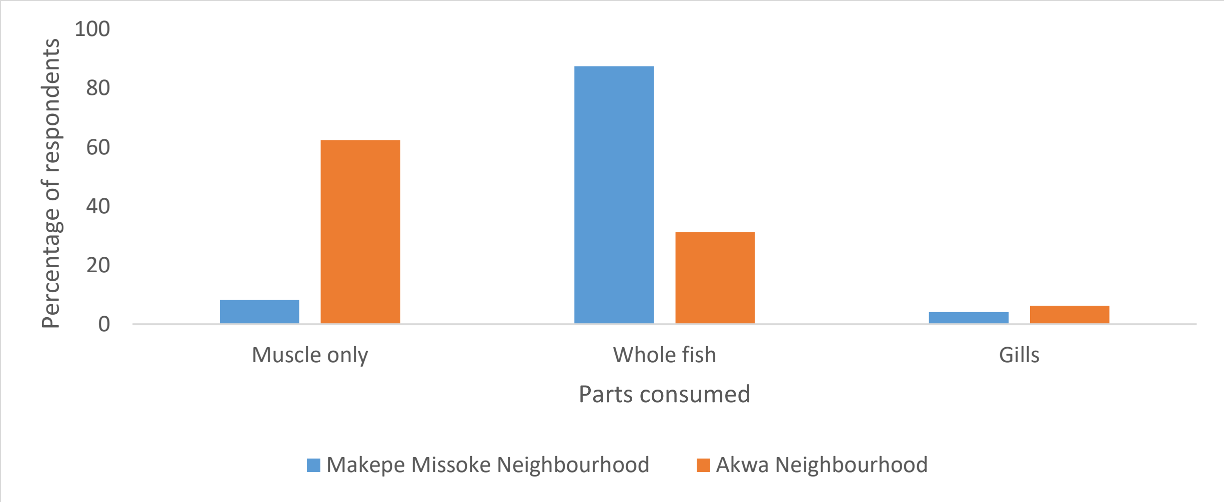


Figure 2. 5: Preferred parts of bonga consumed in the Akwa and Makepe Missoke Neighbourhood.

2.5.10 Preferred parts consumed for catfish in the Akwa and Makepe Missoke Neighbourhood

Most people in both neighbourhoods consumed the whole fish. The number of people who ate the muscle and head were similar between the two neighbourhoods (Figure 2.6).

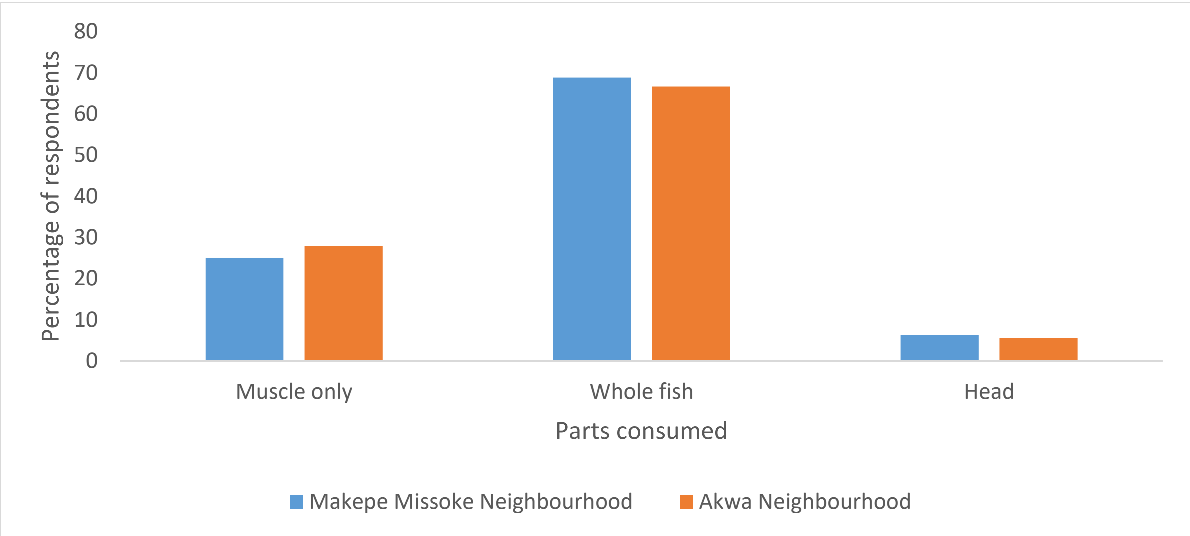


Figure 2. 6: Preferred parts of catfish that are consumed by households in the Akwa and Makepe Missoke Neighbourhood.

2.5.11 Methods of preparing bonga, catfish and shrimp in the Akwa and Makepe Missoke Neighbourhood

The cooking methods for bonga, catfish and shrimp in the Akwa and Makepe Missoke neighbourhood are summarised in Table 2.9. The most common preparation method for all species in both neighbourhood was boiling, followed by frying and then roasting.

Table 2. 9: Preferred preparation methods for shrimp, bonga and catfish in the Akwa and Makepe Missoke Neighbourhoods.

Makepe Missoke Neighbourhood				**Akwa Neighbourhood**		
Methods	Shrimp %	Bonga %	Catfish %	Shrimp %	Bonga %	Catfish %
Boiling	86.4	79.2	81.2	82.6	87.5	86.7
Frying	9.1	16.7	12.5	13.1	12.5	13.3
Roasting	4.5	4.1	6.3	4.3	-	-

2.5.12 Reasons for consuming shrimp, bonga and catfish in the Akwa and Makepe Missoke Neighbourhood

Various reasons were put forward by households for consuming shrimp, bonga and catfish. Taste was the main reason for eating shrimp, bonga and catfish in both neighbourhoods. Although taste was the main reason for eating shrimp, the majority of people in the Akwa neighbourhood indicated that they also eat shrimp because of cultural reasons. They eat shrimp because their ancestors ate shrimp. However, a reasonable number of people in the Makepe Missoke neighbourhood ate shrimp because their family likes it.

Table 2. 10: Reasons for consuming shrimp, bonga and catfish in the Akwa and Makepe Missoke Neighbourhoods.

	Makepe Missoke neighbourhood			**Akwa neighbourhood**		
Reasons	Shrimp%	Bonga %	Catfish %	Shrimp%	Bonga %	Catfish %
It tastes good	40.9	58.3	50	52.2	25	40
My family likes it	31.8	16.7	25	21.7	37.5	27.7
It's healthy	13.6	12.5	18.7	8.7	6.3	13.3
Its readily available	9.1	8.3	6.3	4.3	18.7	20
It's easy to cook	4.5	4.2	-	13.1	12.5	-

2.5.13 Importance of bonga, catfish and shrimp to consumers in the Akwa and Makepe Missoke Neighbourhood

The majority of people in both neighbourhoods stated that shrimp, bonga and catfish was important in their family meals. However, more people in the Akwa neighbourhood stated that shrimp, bonga and catfish was very important in their family meals than those in the Makepe Missoke neighbourhood.

Table 2. 11: Importance of bonga, catfish and shrimp to consumers in the Akwa and Makepe Missoke Neighbourhood.

	Makepe Missoke neighbourhood			**Akwa neighbourhood**		
Importance	Shrimp%	Bonga %	Catfish %	Shrimp%	Bonga %	Catfish %
Very important	31.8	29.2	25	47.8	37.5	40
Important	50	62.5	68.7	39.1	50	46.7
Somewhat important	18.2	8.3	6.3	13.1	12.5	13.3

2.6 Discussion

Consumption rates for bonga in the Makepe Missoke neighbourhood were much higher than in the Akwa neighbourhood. This is because bonga constitute an integral part of most dishes prepared by the majority of people in the Makepe Missoke neighbourhood. Consumption rates for shrimp and catfish were similar between the two neighbourhoods. The amount of fish and shrimp consumption varies in both neighbourhoods, with the highest amount consumed reported in the Akwa neighbourhood. The per capita fish consumption in the Akwa and Makepe Missoke neighbourhoods is 10.7kg/year and 4.9kg/year which is well below the world average of 19.7kg/year (FAO, 2016). Although the per capita consumption of shrimp and fish in these neighbourhoods is below the world average per capita consumption, seafood remain an important sources of animal protein in the Akwa and Makepe Neighbourhoods. This is because the majority of people consumed shrimp and fish.

The result from this survey shows some interesting differences from other surveys conducted in Cameroon in the past. Per capita fish consumption in the Douala's Akwa and Makepe Missoke neighbourhoods were lower than those from previous studies conducted in Cameroon in 1961 and 2010 (Table 2.12). This indicates that, there has been a continuous decline in the per capita consumption of fish in Cameroon.

Table 2. 12: Per capita consumption of fish per person in Cameroon in 1961 and 2010

Year	Per capita consumption in kg per person	Reference
1961	30-48	Belhabib & Paul, 2015
2010	11.7	Belhabib & Paul, 2015

Significant differences were recorded in consumption levels between this study and those conducted in Africa and other countries in South East Asia. Based on results from this study, the per capita fish consumption in the Douala's Akwa and Makepe Missoke neighbourhoods were much higher than those of households in countries like Mongolia, India and Pakistan (Table 2.13). On the other hand, households in countries like Cambodia, Mauritius, Philippines and Thailand recorded a higher per capita fish consumption than those in the Douala's Akwa and Makepe Missoke neighbourhoods.

Table 2. 13: Fish consumption rates in other countries.

Country	Per Capita Consumption in kg	Description	Reference
Mauritius	40	Fish consumption survey	FAO,2013
Bangladesh	11.9	Fish consumption survey	(Needham & Funge-Smith, 2014)
Bhutan	5.58	Fish consumption survey	(Needham & Funge-Smith, 2014)
Cambodia	63.15	Fish consumption survey	(Needham & Funge-Smith, 2014)
India	2.85	Fish consumption survey	(Needham & Funge-Smith, 2014)
Indonesia	12.8	Fish consumption survey	(Needham & Funge-Smith, 2014)
Lao PDR	19.1	Fish consumption survey	(Needham & Funge-Smith, 2014)
Mongolia	0.18	Fish consumption survey	(Needham & Funge-Smith, 2014)
Pakistan	0.6	Fish consumption survey	(Needham & Funge-Smith, 2014)
Philippines	40.2	Fish consumption survey	(Needham & Funge-Smith, 2014)
Sri Lanka	15.3	Fish consumption survey	(Needham & Funge-Smith, 2014)
Timor Leste	6.1	Fish consumption survey	(Needham & Funge-Smith, 2014)
Thailand	31.39	Fish consumption survey	(Needham & Funge-Smith, 2014)
Vietnam	14.6	Fish consumption survey	(Needham & Funge-Smith, 2014)

Interestingly, variation in the size of households and cost (price) of shrimp and fish was directly associated with the amount of bonga, catfish and shrimp consumed. It was observed that bonga, catfish and shrimp were very expensive to purchase in the market. This explains why the majority of households could buy only a small amount of bonga, catfish and shrimp from the market. Therefore, high cost (price) was perceived as a barrier for households to consume bonga, catfish and shrimp. Findings from this study has revealed that taste, household size and cost (price) emerged as the dominant factors influencing the consumption of shrimp and fish in the Akwa and Makepe Missoke neighbourhoods. Availability and accessibility to shrimp, bonga and catfish by households were both important factors influencing the consumption of shrimp and fish consumption in the Akwa and Makepe Missoke neighbourhood. Similarly cost (price) was recorded as a dominant factor influencing fish consumption in Lithuania, Bulgaria, Romania, Slovenia, UK and Croatia (EUMOFA, 2017). Income is also a dominant factor influencing the consumption of fish. Studies conducted in the urban areas of Antalya in Turkey have confirmed that income was an important factor influencing fish consumption (S. Yilmaz, Sen, Kara, & Ali, 2014)

The most common preparation method for all species in both neighbourhoods was boiling, followed by frying and then roasting. However, most people did not prefer frying because frying requires a lot of oil. Frying fish at home was not economical for many families in these neighbourhoods based on the price of oil. The majority of people preferred boiling because it was an excellent method for preparing most traditional dishes. In addition, most households stated that boiling keeps flavourful juices and nutrients inside the soup, rather than letting them escape into the surrounding cooking liquid. The survey also found that some consumers prefer roasting. In regards to the parts of the fish people are eating, it was noticed that the majority of people in both neighbourhoods consumed the whole fish. However, a small percentage of people consumed the head and gills.

Eating seafood regularly has been demonstrated to provide many essential nutrients important for maintaining health. However, the consumption of contaminated seafood (e.g. shrimp and fish) might affect the health of consumers due to exposure to contaminants. Despite the many health benefits for eating seafood, it is evident that most people interviewed during the survey were not aware of the health benefits associated with the consumption of shrimp and fish. In addition, many of the survey respondents did not know that they are vulnerable to contaminants in seafood. Most of them ate shrimp and fish because it tastes good or their ancestors have been eating them.

The scope of this study was focused only on two neighbourhoods in the city of Douala, whereas a much more complete survey is needed in the city to give a broader information on fish consumption. Therefore, data collected from this survey cannot be fully generalised for the entire city of Douala. This study did not explore households income which can be helpful in future studies to monitor fish consumption rates in these neighbourhoods. Observations from the current household fish consumption study indicates that income growth (and/or an improvement in households income) may contribute to greater consumption of shrimp and fish in the Douala’s Akwa and Makepe Missoke neighbourhoods. With an improvement of household income, the current consumption trends of shrimp and fish in these neighbourhoods could increase in the near future depending on the shifts in relative prices of shrimp and fish.

It is evident that per capita consumption of fish is declining in Cameroon. As a result, research should be conducted in the future to determine the cause of the decline. In addition, research should also be carried out on consumer attitudes towards the consumption of other animal protein like meat and imported frozen chicken to determine if they are affecting consumption rates for shrimp and fish. This survey was limited to only two neighbourhoods in the city of Douala. Therefore, future research is needed to obtain data on the consumption of fish and shrimp for the entire city of Douala.

2.7 Conclusions

The majority of people in the Akwa and Makepe Missoke neighbourhood consumed bonga, catfish and shrimp. Although most people in both neighbourhoods consumed fish and shrimp, per capita consumption has continued to decline.

Household size and cost (price) were a major determinant factors of fish consumption rates in these neighbourhoods, with most people with large family size purchasing more fish. Taste and cultural factors also played an active role in fish consumption. Different cultures in both neighbourhoods had different behaviours and attitudes towards food preparation and consumption.

This study has provided useful information about fish and seafood consumption in the Douala's Akwa and Makepe Missoke neighbourhoods. Therefore data from the study can be used to complement similar food consumption surveys conducted by other researchers at the national level in the past.

3 Materials and Methods

3.1 Sample Collection and Storage

Sediment and biota samples were collected from the Wouri Estuary in Cameroon before being dried and shipped back to New Zealand for analysis. A research permit was obtained from the Ministry of Scientific Research in Cameroon to collect samples. The samples were imported into New Zealand under a Ministry for Primary Industries permit held by the School of Biological Sciences.

3.2 Sample sites

Nineteen sites including control sites were selected for sampling (Figure 3.1). These sites were chosen based on human activities in the area, ecological settings and environmental considerations (Table 3.1). Most of the sites are close to mangroves which are nursery grounds for shrimps and fish. These sites are also considered as high areas of deposition where small sediment particulates accumulate (Giresse & Cahet, 1997).

Table 3. 1: Description of sample sites in the Wouri Estuary, Cameroon

Type of Environment	Site number	Environmental Significance
Freshwater	Sites 3, 6, 12 and 13	Site 3, 12 and 13 receive direct run-off water from the municipality and waste discharges from industries. Site 6 receives run-off from agricultural land.
Brackish Water	Sites 1, 2, 4 and 5	Sites 1 and 2 are fishing port and beach market. No tidal influence, used as dumping ground for rubbish and sewage. Receives direct run off water from the municipality. Sites 4 and 5 receives urban run-off and industrial discharge. High tidal influence.
Marine/Brackish Water	Sites 10, 11, 14, 15, 16, 17, 18 and 19	Oceanic influences with high tidal effects
Marine Coastal Area	Sites 7, 8 and 9	Receive urban run-off and discharge from the Tiko municipality

Figure 3. 1: Sampling sites in the Wouri Estuary (Cameroon Estuary).

Figure 3. 2: Location of study area

Source: mapsofworld.com/cameroon/maps/cameroon-river-map.jpg.

3.3 Sediment Samples

Sediment samples were collected from 19 sites in the Wouri Estuary (Figure 3.1). Three sediment samples were collected from an area of about 40 x 40 cm at each site. The top 5cm of sediment was collected using a stainless steel spoon during low tides. The stainless steel spoon was rinsed thoroughly with water between each site to ensure that it did not transfer contamination to the sediment at the next sampling site. The sediment samples were kept in a sealed plastic bags, placed in an ice box at about 4ºC before being transported to the laboratory. Approximately 990g of wet sediment from each sample was placed in a plastic container. The sediment samples were oven dried at 40°C until a constant dry weight was obtained. The sediment samples were ground with a pestle in an agate mortar to a size less than 2mm and sieved in a 2mm nylon-sieve cloth held in a plastic frame. The sediment samples were stored in air tight plastic bags before being shipped to New Zealand for analysis.

3.4 Biological Samples

Sixteen fresh shrimp (*Penacus kerathusus*) were collected using a fishing net from the same sites as the sediment samples. One shrimp sample was collected from each site. The shrimp were placed in labelled bags and stored on ice immediately after collection, before being lab dried and shipped to New Zealand for laboratory analysis. The lab drying was carried out in an oven at 60°C. The drying temperature did not exceed 60°C to minimize evaporative loss of volatile analytes such as mercury (Puget Sound Protocols, 1997).

Eight fresh catfish (*Arius heudelotii Valenciennes, 1840*) and eight fresh bonga (*Ethmalosa fimbriata*) caught from the estuary by local fishermen were purchased at two commercial fishing markets in Douala. The fresh fish were placed in labelled bags and stored on ice immediately after buying. The fresh fish samples were dissected and the muscle, gills and livers were lab dried at 60°C before being shipped to New Zealand for analysis.

Eight samples of locally dried shrimp were purchased from four different vendors in the city of Douala. Eight samples of locally dried fish (Bonga-*Ethmalosa fimbriata* and Catfish- *Arius heudelotii Valenciennes, 1840*) were purchased from food markets in Douala. The locally dried samples were shipped to New Zealand for analysis. Each of the oven dried and locally dried seafood samples were blended to a homogeneous mixture using a blender with stainless steel blades. The homogenized samples were transferred into falcon tubes using a clean plastic spoon. The blender and plastic spoon were properly cleaned with 70% Ethanol to avoid cross contamination between samples.

3.5 Trace element analysis

3.5.1 Sediments

3.5.2 Total recoverable trace elements

Prior to ICP-MS analysis, sediment samples were prepared using a modified version of USEPA 200.8 (Chandurvelan, Marsden, Glover, & Gaw, 2015) . Approximately 0.95-1.05g of each sample was weighed into an acid washed polycarbonate tubes and 4 ml of concentrated ultra-pure nitric acid and 10 ml of concentrated ultra-pure hydrochloric acid was added to digest the samples and left to stand overnight. The samples were refluxed in a heating block at 85^{o}C for 40 minutes. After heating, samples were allowed to cool to room temperature and the tubes were made up to 20ml with Milli-Q water while swirling gently to ensure mixing. Samples were then left to stand overnight to settle out the particulates. Samples were diluted by adding 0.5ml to 10ml of 2% nitric acid. Each digestion batch included a certified reference material (Standard Reference Material 2702 Inorganic in Marine Sediment) prepared in duplicate. Two blank samples were prepared in the same manner as samples for each batch of analysis. The certified reference material was used to demonstrate accuracy of the method and the blanks to assess and control the degree of contamination throughout the analytical process.

3.5.3 Method for HCl leach

Approximately 500 mg of each sediment sample was weighed into centrifuge tubes and 50 ml of 1M HCL was added to each tubes (Allen, Fu, & Deng, 1993) . 50 ml of 1M HCL was also added to two empty tubes as blank samples. The tubes were attached to an end-over-end mixer. The mixer was turned to rotate to a slow speed (approximately less than 60 rpm) and left overnight (16 hours). Samples were removed from the mixer and left to settle before 1 ml of each sample was transferred into ICP-MS tubes and then diluted with 9 ml of 2% nitric acid, or 0.1% aqua regia/cysteine. Aqua regia/cysteine was used for Hg analysis while 2% nitric acid was used for As, Cd, Cr, Cu, Ni, Pb and Zn analysis.

3.5.4 Loss on Ignition method

A modified method from Dean Jr (1974) was used to measure loss on ignition. The samples were autoclaved at 121°C for about 30 minutes. Approximately 5 g of dried sediments was weighed from each sample and placed in pre-weighed and cleaned silica dishes. The samples were heated in muffle-furnace at 550°C for 4 hours and left in the muffle-furnace overnight to cool. Once cooled, samples were weighed again and the loss in mass converted to a percent organic matter. The percentage organic matter was calculated using the following equation.

$$\%\ \text{Organic matter} = \frac{\text{Difference between sediment weight}}{\text{Original weight } (\tilde{\ }5\text{g})} \times 100$$

3.5.5 Biota

Biota samples (shrimp, bonga and catfish) were prepared for ICP-MS analysis. Firstly, samples were ground using a moulinex (original grinder), then 0.2 g of each sample was weighed into polycarbonate tubes and 1 ml of concentrated ultrapure nitric acid and 0.2 ml of concentrated ultrapure hydrochloric acid was added and the samples left to stand overnight. The samples were heated on the hotplate in a heating block at 85°C for 40 minutes until refluxing. The samples were allowed to cool at room temperature and the tubes were made up to 20 ml with ultra-pure water while swirling gently to ensure mixing. Samples were left overnight to settle out particulates. Finally, 1 ml of each sample was diluted with 4 ml of 2% nitric acid, 0.5 hydrochloric acid and L-cysteine. The samples were then inverted to mix then submitted for ICP-MS analysis. Three certified reference materials (Bovine liver, National Research Council Canada Dorm-4 Fish and National Institute of Standards and Technology Standard Reference Material 2976 Mussel Tissue) were used and prepared in duplicate for each digestion batch. Two blank samples was prepared in a similar manner as samples for each batch of analysis.

3.5.6 Sample pretreatment

The effect of sample pre-treatment on trace element concentrations was investigated. Fourteen shrimp samples were purchased from the supermarket in New Zealand. Each shrimp was weighed into a polycarbonate vial. After weighing, seven shrimp samples were lab dried in an oven at 60°C for 3 days. The remaining seven shrimp were frozen in the polycarbonate vial before being freeze dried (Labconco 2.5 Liter Benchtop Freeze Dryer). The freeze drying was carried out at -45°C for 3 days.

3.5.7 QA/QC Results

The percentage differences for the duplicates ranged from 2 to 14 (Table 3.4). Recoveries for analysis of CRMs ranged from 80% to 103% (Table 3.2). The detection limits were calculated as three times the standard deviation of the blanks and were compared to the standards of every run (Table 3.3). If the calculated detection limit lower than the lowest standard, the lowest standard was used as the detection limit. All the values for blanks were below detection limits other than Zn.

3.5.8 ICP-MS analysis

Samples were analysed using an Agilient 7500 Series ICP-MS (Inductively Coupled Plasma-Mass Spectrometry) with an octopole reaction system with helium as the collision gas at the University of Canterbury. A water certified reference material, IV SRm 1643, was analysed with each analytical run and an internal standard (^{103}Rh) was introduced online. The isotopes measured were ^{107}Ag, ^{27}Al, ^{75}As, ^{44}Ca, ^{111}Cd, ^{59}Co, ^{53}Cr, ^{63}Cu, ^{57}Fe, ^{24}Mg, ^{55}Mn, ^{60}Ni, ^{208}Pb, ^{121}Sb, ^{51}V, ^{66}Zn.

Table 3. 2: Percentage recoveries of certified reference material

			Trace element							
CRM Name	Sample Type		As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Inorganics in Marine	Sediment	Mean recoveries	82.4	94.8	80.3	83.4	87.9	82.4	94.4	81.8
Mussel Tissue	Shrimp,Catfish Bonga	Mean recoveries	94	87.2	84.2	83.6	85.7	82.3	86.7	91.7
Dorm 4 Fish	Bonga and Catfish Muscl	Mean recoveries	92.8	90.4	86.5	89.9	85.3	88.3	90.6	91.3
Bovine Liver	Bonga and Catfish liver	Mean recoveries	88.4	88.5	93.8	84.6	85.8	90	98.4	87.7

Table 3. 3: Detection limits in ug/g of As, Cd, Cr, Cu, Hg, Ni, Pb and Zn for the different sample types

	Trace element							
Sample type	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Sediment	0.019	0.0004	0.4	0.4	0.4	0.4	0.018	0.18
Shrimp	0.11	0.028	0.06	0.19	0.01	0.1	0.035	0.5
Bonga and Catfish	0.07	0.005	0.09	0.07	0.5	0.4	0.06	0.5

Table 3. 4: Percentage differences for duplicates

	Trace element							
Sample Types	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Sediment	5	14	10	4	6	9	12	8
Shrimp	3.4	2	8	4	6	10	8	3
Catfish/Bonga Muscles	4	5	9	8	7.2	8	11	4
Catfish and Bonga Gill	4	4	10	5	9	6	7	5
Catfish/Bonga liver	3	12	6	11	4	4	7	11

3.5.9 Assessment of sediment contamination using geoaccumulation index

The geoaccumulation index (Igeo) was used to assess the amount of trace elements in sediment that were from terrestrial origin. The Igeo was calculated using the mathematical equation:

Igeo = $\log_2$ (Cn/1.5Bn) (Yaqin et al., 2008)

Where:

Cn: Total concentration of the element in sediment analysed in ug/g

Bn: Background content of trace elements in this study. The background trace elements concentration used was the lowest concentration of each element (Table 4.2).

3.5.10 Statistics

Statistics were analysed using Excel 2013. Analysis of variance (ANOVA) were performed to compare the concentrations of trace elements in the different samples. Pearson's correlations between trace elements and OM were performed. Paired t-tests were used to determine the effect of sample pre-treatment on trace element concentrations were performed. Where the values were less than detection limit, half the detection limit was used. Data sets were only analysed statistically when 50% of the samples were greater than detection limit.

4. Results

4.1 Introduction

Trace elements are of increasing concern for sediment and aquatic organisms in marine and freshwater systems. Trace elements have been detected in estuaries and coastal marine environment in many overseas countries. They have been found in a wide range of aquatic organisms including fish, crabs and shrimp. Due to their toxicity, abundance, persistence, and subsequent bio-accumulation, they are one of the most common pollutants which have severely deteriorated the aquatic ecosystems (Ali, Malik, & Qadir, 2013). Both natural and anthropogenic processes have triggered their release in marine and freshwater systems (Zhang, Guo, Meng, & Wang, 2009). Trace elements when discharged into coastal marine environment can accumulate in sediment and biomagnified along the aquatic food chains (Yi, Yang, & Zhang, 2011). Sediment, fish and shrimp can be used to determine the concentrations of trace element deposited in aquatic ecosystem over a period of time.

Trace elements have been found to accumulate in soil in the city of Douala. Asaah et al., 2006 measured high concentrations of Cd, Cr, Ni, Pb and Zn in soil samples from the Bassa industrial zone in the city of Douala. This indicates that the Wouri Estuary is subject to industrial and other anthropogenic effluents. Very little research has been undertaken to determine the concentrations of trace element in sediment and biota in the Wouri Estuary.

4.2 Objectives

The objectives of this study were:

-To determine spatial variability in sediment trace element concentrations in the Wouri Estuary, Cameroon;

-To determine concentrations of trace elements in shrimp and fish (bonga-*Ethmalosa fimbriata*/catfish) in the Wouri Estuary;

-Undertake a health risk assessment for the consumption of shrimp and fish sourced from the Wouri Estuary; and

-To determine the effect of sample pre-treatment on trace element concentrations in biota.

4.3 Sediment

4.3.1 Trace element concentrations in sediment samples from the different types of environment in the Wouri Estuary.

The concentration of trace elements in the sediment followed the order Cu>Cr>Zn>Ni>Pb>As >Cd. The concentrations of Cu in the coastal marine area were greater than those in freshwater, brackish water and marine/brackish water (Table 4.1). Less distinct spatial differences in concentrations were observed for As, Pb, Cd, and Cr in the samples from coastal marine area and marine/brackish water.

The data for the sediment samples collected from the different types of environment in the Wouri Estuary were analysed using ANOVA. Higher concentrations of As, Cr, Ni, Pb and Zn were measured for brackish water sites compared to freshwater environment, marine/brackish water and coastal marine area. The concentrations of Zn in the different types of environment were statistically significant with the highest concentrations at site 1, followed by site 2 and 9, and then site 6 ($p<0.05$). The concentration of Cd measured at sites in brackish water was higher than those measured in freshwater, marine/brackish water and coastal marine area.

Table 4. 1: Mean trace element concentrations in sediment samples (ug/g) from the different types of environment in the Wouri Estuary

		Trace element						
Type of Environment	Site number and Mean concentrations	As	Cd	Cr	Cu	Ni	Pb	Zn
Freshwater	Sites 3, 6, 12 and 13	8	0.04	73.2	19.2	21.8	18	56.9
Brackish Water	Sites 1, 2, 4, and 5	9	0.06	76.5	22.1	22.3	21	68.6
Marine/Brackish	Sites 10, 11, 14, 15, 16, 17, 18, 19	7.1	0.04	58.7	14.9	16.7	15	46.5
Marine Coastal Area	Sites 7, 8 and 9	7	0.05	57.8	60.8	19.7	15	59.4

The concentrations of Cd, Cr, Ni and Zn in surface sediment from the Wouri Estuary were typically higher where the Mungo River discharges (Site 6) compared to where the Wouri River (Site 4) and Dibamba River (Site 12) discharge. The concentration of As was higher where the Wouri River discharges compared to the Mungo and Dibamba Rivers. Most of the sample sites had trace element concentrations that were higher than the control sites (Table 4.2). The Hg results were below the detection limit in all sediment samples.

4.3.2 Comparison to guidelines

The Australian and New Zealand Guidelines for Fresh and Marine Water Quality were used to assess the concentration of trace elements in sediment from the Wouri Estuary as there are no sediment quality guidelines available for Cameroon. The Australian and New Zealand Environment and Conservation Council (ANZECC) has derived a low interim sediment quality guideline value (ISQG-Low) and a high interim sediment quality guideline value (ISQG-High) for each trace element (Table 4.2). None of the samples collected from the Wouri Estuary had trace elements concentrations that exceeded the ANZECC Interim Sediment Quality Guideline High (ANZECC, 2000). However, concentrations of Cr, Cu and Ni exceeded the ANZECC Interim Sediment Quality Guideline Low at some sites (Table 4.2).

Table 4. 2: Mean trace element concentrations in sediment samples (ug/g) from the Wouri estuary, Cameroon. Concentrations exceeding the ANZECC Interim Sediment Guideline are highlighted in bold.

	Trace element						
Sites	As	Cd	Cr	Cu	Ni	Pb	Zn
Youpwe (Site 1)	9.3	0.08	**85.7**	26.4	**24.4**	25.4	85.2
Nsengue (Site 2)	9.1	0.07	78.9	23.7	**23.2**	21.1	70.4
Cimencam (Site 3)	7.7	0.04	68.4	18.1	19.9	18.1	54.9
Bwape (Site 4)	10.6	0.05	**82.6**	23.2	**24.4**	21.6	65.8
Koo (Site 5)	7.1	0.04	58.8	15.1	17.1	16.1	53.1
Kombo (Site 6)	7.2	0.06	78.8	22.6	**25.7**	19.7	66.7
Bouma (Site 7)	4.2	0.04	41.3	9.2	14.3	8.2	44.2
Moungongue (Site 8)	9.5	0.06	50.2	**150.7**	17.3	17.9	63.5
Wengue (Site 9)	7.5	0.06	**81.9**	22.7	**27.4**	19.3	70.4
Acre (Site 10)	9.2	0.06	45.9	13.9	15.2	15.2	48.7
K. Moukoko (Site 11)	9.9	0.06	70.9	21.8	**22.3**	17.6	60.2
Missipi (Site 12)	8.1	0.03	64.4	15.3	18.5	15.7	47.2
Dongo (Site 13)	8.1	0.03	**81.2**	20.8	**23.1**	20.1	58.9
Manoka (Site 14)	8.2	0.03	55.9	13.6	15.6	13.8	43.1
Entrée Epassi (Site 15)	4.8	0.01	32.6	4.9	8.9	5.8	34.8
Epassi (Site 16)	7.6	0.03	75.1	18.6	20.6	18.8	52.4
S. Ganaberi(Site 17)^{C}	6.1	0.03	56.6	13.8	15.1	14.4	39.7
Entrée Mbiako (Site 18)^{C}	6.9	0.04	**83.1**	21.2	**22.7**	20.6	58.3
Mbeguerekume (Site 19)^{C}	4.1	0.03	49.5	12.1	13.1	11.3	34.5
ISQG-Low (Trigger value)	20	1.5	80	65	21	50	200
ISQG-High	70	10	370	270	52	220	410

ANZEEC Interim Sediment Quality Guideline (ISQG)
17^{c}, 18^{c} and 19^{c} are control sites. "C" stand for control

4.3.3 Geoaccumulation index for sediments from the Wouri Estuary, Cameroon

The Geoaccumulation index was used to determine the elements most enriched in sediment from the Wouri Estuary. The identified elements of concern with Igeo values greater than 1 were Cd, Cu and Pb. These values were greatest in sediment collected from sites that receive direct run-off water from the municipality, sewage and waste discharges from industries. Most of these sites were located close to urbanised areas and where the Wouri, Mungo and Dibamba Rivers discharge.

Table 4.3: Geoaccumulation index for sediments from the Wouri Estuary, Cameroon

	Trace element						
Sites	As	Cd	Cr	Cu	Ni	Pb	Zn
Youpwe (Site 1)	0.61	**1.99**	0.81	**1.83**	0.86	**1.52**	0.72
Nsengue (Site 2)	0.56	**1.94**	0.69	**1.67**	0.79	**1.26**	0.44
Cimencam (Site 3)	0.34	**1.05**	0.48	**1.27**	0.57	**1.04**	0.08
Bwape (Site 4)	0.79	**1.50**	0.75	**1.64**	0.86	**1.29**	0.34
Koo (Site 5)	0.23	**1.12**	0.27	**1.01**	0.35	0.86	0.04
Kombo (Site 6)	0.25	**1.71**	0.69	**1.61**	0.94	**1.16**	0.37
Bouma (Site 7)	-0.55	**1.07**	-0.24	0.32	0.09	-0.11	-0.23
Moungongue (Site 8)	0.64	**1.83**	0.04	**4.34**	0.37	**1.03**	0.29
Wengue (9)	0.31	**1.72**	0.74	**1.61**	**1.03**	**1.13**	0.44
Acre (10)	0.59	**1.73**	-0.08	0.91	0.19	0.79	-0.09
Kombo Moukoko (Site 11)	0.71	**1.82**	0.53	**1.55**	0.73	0.99	0.22
Missipi (Site 12)	0.40	0.99	0.39	**1.04**	0.47	0.83	-0.13
Dongo (Site 13	0.41	**1.01**	0.73	**1.49**	0.78	**1.18**	0.19
Manoka (Site 14)	0.46	0.64	0.19	0.87	0.22	0.65	-0.27
Entrée Epassi (Site 15)	-0.33						-0.57
Epassi (Site 16)	0.33	-0.47	0.01	0.04	0.06	0.15	0.01
S. Ganaberi (Site 17)	-0.008	-0.58	-0.39	-0.39	-0.39	-0.24	-0.38
Entrée Mbiako (Site 18)	0.18	-0.38	0.16	0.23	0.21	0.28	0.17
Mbeguerekume (Site 19)		-0.58	-0.58	-0.58	-0.58	-0.58	

Table 4. 4: Geoaccumulation index (Igeo) and the degree of trace element contamination

Igeo value	Igeo class	Sediment
Igeo ≤0	0	Practically unpolluted
0<Igeo<1	1	Unpolluted to moderately polluted
1<Igeo<2	2	Moderately polluted
2<Igeo<3	3	Moderately to strongly polluted
3<Igeo<4	4	Strongly polluted
4<Igeo<5	5	From strongly to extremely polluted
Igeo≥5	6	Extremely polluted

Source (Yaqin et al., 2008)

4.4.4 Sediment (HCl Leach)

The results from the HCl analysis indicated that As, Cd, Cr, Cu, Ni, Pb and Zn in sediments are available for uptake by organisms. A significant percentage of Cd, Cu, Pb and Zn in sediment was potentially bioavailable in the Wouri Estuary. More than half (58%) of Ni in sediment were bioavailable for uptake by organisms. Similar percentages of As and Cr in sediment were bioavailable in the Wouri Estuary.

Table 4. 5: Mean percent bioavailable for trace elements in surface sediments (ug/g) from the Wouri estuary

Trace elements	% Bioavailable
As	38
Cd	95.3
Cr	41.4
Cu	108
Ni	58
Pb	76
Zn	83

4.4.5 Organic matter

The percentage of organic matter in the Wouri Estuary sediments ranged between 4.9 and 24.1 (Table 4.6), with the highest percentage being recorded at site 3 very close to the city of Douala. The lowest percentage was recorded at site 15 which is located close to the control sites. Higher organic matter were found in most freshwater sites which are closer to people/urban areas.

Table 4. 6: Percentage organic matter in sediment from the Wouri Estuary.

Sites	Loss in mass	Percent organic matter(%OM)
Youpwe (Site 1)	1.03	20.5
Nsengue (Site 2)	0.92	18.3
Cimencam (Site 3)	1.22	24.1
Bwape (Site 4)	1.05	20.6
Koo (Site 5)	0.72	13.9
Kombo (Site 6)	1.14	21.7
Bouma (Site 7)	0.49	9.5
Moungongue (Site 8)	0.76	14.8
Wengue (Site 9)	1.14	22
Acre (Site 10)	0.93	18.1
K. Moukoko (Site 11)	1.07	21.3
Missipi (Site 12)	0.77	14.9
Dongo (Site 13)	1.19	23.7
Manoka (Site 14)	0.88	17.5
Entrée Epassi (Site 15)	0.26	4.9
Epassi (Site 16)	1.10	21
S. Ganaberi (Site 17	0.89	17.9
Entrée Mbiako (Site 18)	1.12	21.4
Mbeguerekume (Site 19)	0.94	18.1

4.4.6 Correlations between trace elements and organic matter (OM)

Concentrations of Cr, Ni, Pb and Zn increased with organic matter ($p<0.05$). Concentrations of As, Cd, Cr, Ni, Pb and Zn were significantly correlated indicating a common source (Table 4.7).

Table 4. 7: Correlations between trace elements and organic matter in sediments from the Wouri Estuary, Cameroon

	As	Cd	Cr	Cu	Ni	Pb	Zn	Fe	OM
As	1								
Cd	**0.64^x**	1							
Cr	**0.53^x**	**0.49**	1						
Cu	0.36	0.40	-0.05	1					
Ni	**0.58^x**	**0.65^x**	**0.95^x**	0.07	1				
Pb	**0.73^x**	**0.69^x**	**0.91^x**	0.23	**0.88^x**	1			
Zn	**0.66^x**	**0.82^x**	**0.78^x**	0.31	**0.86^x**	**0.88^x**	1		
Fe	**0.69^x**	0.45	**0.89^x**	-0.07	**0.81^x**	**0.86^x**	**0.72^x**	1	
OM	0.47	0.39	**0.81^x**	-0.02	**0.77^x**	**0.78^x**	**0.53^x**	**0.65^x**	1

Significant values in bold
$P<0.05$ ^{x}
$P<0.01^{xx}$, $P<0.001$ ^{xxx}

4.4 NZ Shrimp

The concentrations of Cd and Cu in the oven dried shrimp and freeze dried shrimp were significantly different ($p<0.05$). There were no differences in the concentrations of As, Cr, Ni, Hg, Pb and Zn between the oven dried shrimp and the freeze dried shrimp.

Table 4. 8: Comparision of trace element concentrations (ug/g) in the oven dried shrimp and freeze dried shrimp

		Trace element							
		As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Oven Dried Shrimp	Mean	2.7	0.09	0.79	68.8	0.03	0.51	0.17	53
Freeze Dried Shrimp	Mean	2.6	0.16	0.68	74.9	0.03	0.43	0.17	58
P-values		0.2	0.02	0.3	0.04	0.4	0.1	0.3	0.07

4.5 Cameroon Shrimp

4.5.1 Fresh shrimp

The concentrations of trace elements in shrimp followed the order Zn > Cu > As > Cr >Ni >Hg > Pb and Cd. The highest concentration of As were measured in shrimp collected from site 15. The concentrations of As measured in most shrimp collected from sites in freshwater water were similar to those collected from most sites in brackish water and some sites in coastal marine areas (Table 4.10). Higher concentrations of Cd were measured in shrimp collected from site 14. Most shrimp collected in brackish water and marine/brackish had similar concentrations of Cd (Table 4.10). Relatively high concentrations of Zn were measured in shrimp sampled in freshwater (site 13) than those from brackish water, coastal marine areas and marine/brackish water. The highest concentration of Cu were found in shrimp collected from site 14 (Table 4.9).

Table 4. 9: Concentration of trace elements (ug/g wet weight) in fresh shrimp collected from the Wouri Estuary, Cameroon

Wet weight	Trace element							
Sites	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Bwape (4)	0.79	0.008	0.17	5.05	0.02	0.06	0.02	14.49
Koo (5)	1.51	0.004	0.07	4.76	0.02	0.04	0.01	14.82
Kombo (6)	0.94	0.007	0.05	4.88	0.01	0.01	0.002	12.44
Bouma (7)	0.40	0.002	0.04	2.09	0.01	0.02	0.01	8.49
Moungongue (8)	1.56	0.006	0.03	6.58	0.02	0.02	0.003	17.19
Wengue (9)	0.59	0.004	0.14	1.50	0.01	0.07	0.024	8.51
Acre (10)	0.49	0.004	0.04	1.43	0.01	0.04	0.013	11.87
K. Moukoko (11)	0.92	0.007	0.05	6.87	0.01	0.04	0.01	12.81
Missipi (12)	1.24	0.006	0.07	7.84	0.02	0.03	0.01	15.97
Dongo (13)	1.90	0.008	0.12	9.56	0.02	0.06	0.02	18.61
Manoka (14)	1.79	0.011	0.05	9.74	0.03	0.03	0.01	16.95
Entrée Epassi (15	2.51	0.008	0.07	5.91	0.02	0.04	0.01	16.95
Epassi (16)	0.94	0.005	0.03	4.21	0.01	0.01	0.004	12.03
S. Ganaberi (17)	0.95	0.003	0.11	4.58	0.01	0.03	0.01	12.70
Entrée Mbiako (18	2.26	0.009	0.06	5.92	0.01	0.05	0.01	14.95
Mbeguerekume (19	1.94	0.006	0.13	5.29	0.01	0.04	0.01	13.82

Table 4. 10: Mean trace element concentrations in shrimp samples (ug/g wet weight) from the different types of environment in the Wouri Estuary

Wet weight		Trace element							
Type of Environment	Sites/ Mean concentrations	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Freshwater	Sites 6, 12 and 13	1.4	0.007	0.1	7.4	0.02	0.03	0.01	15.7
Brackish Water	Sites 4, and 5	1.2	0.006	0.1	5	0.02	0.05	0.02	14.7
Marine/Brackish	Sites 10, 11, 14, 15, 16, 17, 18, 19	1.5	0.007	0.07	5.5	0.01	0.04	0.009	14
Marine Coastal Area	Sites 7, 8 and 9	0.9	0.004	0.07	3.4	0.01	0.04	0.01	11.4

4.5.2 Locally dried shrimp

Trace element concentrations in the locally dried shrimp from the different markets followed the order Zn > Cu > As >Cr > Ni > Pb > Cd and Hg. The concentrations of As, Cr, Ni and Zn in locally dried shrimp from the different markets were statistically significant ($p<0.05$). The highest concentrations of As, Cr and Ni were measured in shrimp from the Bonasama market while the highest concentrations of Zn was measured in shrimp from the Youpwe market.

Table 4. 11: Mean concentration of trace elements (ug/g dry weight) in locally dried shrimp collected from local markets in Douala, Cameroon

	Dry weight	Trace element							
Markets	Locally Dried shrimp	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Deido	Mean	5.37	0.05	0.40	26.52	0.07	0.29	0.18	42.3
Youpwe	Mean	8.80	0.05	0.91	23.51	0.07	0.46	0.22	53
Bonasama	Mean	10.76	0.08	1.58	22.77	0.06	0.52	0.18	56.6
Makepe M.	Mean	7.84	0.05	0.90	18.79	0.05	0.41	0.26	50.2
P-value		0.002	0.15	0.01	0.1	0.3	0.008	0.3	0.001

4.6 Catfish

4.6.1 Fresh catfish

Trace elements accumulation in the liver, gill and muscle of catfish (*Arius heudelotii Valenciennes, 1840)* followed the order Zn > Cu >As>Pb>Cd (Table 4.12). Hg and Ni were below the limits of detection in all the organs of the samples studied. Pb and Cd were also below the detection limits in the muscle. The organ with the highest concentrations of Cr was the gill, followed by the muscle and then the liver ($p<0.05$). The concentrations of Cu and Zn in the fish organs (muscle, gill and liver) were statistically significant ($p<0.05$). The liver had the highest concentrations of Cu and Zn, followed by the gill and then the muscle. Paired t-tests identified significant differences in the concentrations of Cd in the fish organs (liver and gills, $p<0.05$). The highest concentrations of Cd were measured in the liver.

Table 4. 12: Mean Concentration of trace elements (ug/g wet weight) in fresh catfish purchased from fishing markets along the Wouri Estuary (Base Naval)

Fresh	Wet weight ug/g	Trace element							
Parts	Fresh Catfish	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Muscle	Mean	0.09	<DL	0.08	0.14	<DL	<DL	<DL	5.1
Gills	Mean	0.13	0.004	0.13	0.46	<DL	<DL	0.07	13.2
Liver	Mean	0.19	0.12	0.13	17.9	0.37	<DL	0.013	56.1

4.6.2 Locally dried catfish

Trace element concentrations in locally dried catfish followed the order Zn>As>Cr>Cu>Pb>Cd in samples purchased from Deido market and Zn>Cr>Cu>Ni>As>Pb>Cd in samples from Youpwe. The concentrations of As and Zn in locally dried catfish from Deido market were higher than those from Youpwe. Hg and Ni were not detectable in locally dried catfish from Deido market. Hg was not also detected in catfish samples collected from Youpwe market.

Table 4. 13: Mean Concentration of trace elements (ug/g dry weight) in locally dried catfish purchased from markets in Deido and Youpwe

Locally dried	Dry weight ug/g	Trace element							
Markets	Catfish Purchased	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Deido	Mean	13.4	0.009	2.1	1.51	<DL	<DL	0.11	99.7
Youpwe	Mean	0.61	0.022	1.9	1.26	<DL	0.63	0.43	60.1

4.7 Bonga *(Ethmalosa fimbriata)*

4.7.1 Fresh Bonga

Trace element concentrations in the muscle of bonga from the Wouri Estuary were measured in the following order Zn>Cu>As>Cr>Cd with Hg, Ni and Pb not detected in the muscle samples. The order of trace elements in the gill was Zn>As>Cu>Cr>Pb>Cd with Hg and Ni not detected in the gill samples. In the liver, the order of elements was Zn>Cu>As>Cr>Pb>Cd with Hg and Ni not detected. The highest concentrations of Zn, Pb, Cu, Cr, Cd and As were found in the liver and the lowest concentrations in the muscle with the exception of Cu that was higher in the muscle than in the gill. The highest concentrations of Cd, Cu and Zn were present in the liver, followed by the gill and muscle ($p<0.05$).

Table 4. 14: Mean Concentration of trace elements (ug/g wet weight) in fresh bonga purchased from fishing market along the Wouri Estuary (Youpwe)

Fresh	Wet weight ug/g	Trace element							
Parts	Fresh Bonga	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Muscles	Mean	0.3	0.002	0.05	0.33	<DL	<DL	<DL	5.9
Gills	Mean	0.4	0.007	0.10	0.27	<DL	<DL	0.05	22.4
Liver	Mean	1.6	0.106	0.62	9.5	<DL	<DL	0.15	58.2

4.7.2 Locally dried bonga

Trace elements in the locally dried bonga purchased from markets (Deido and Youpwe) in the city of Douala followed the order Zn>As>Cu>Cr>Ni>Pb>Cd in samples purchased from Deido market and Zn>Cu>As>Cr>Ni>Pb>Cd in samples from Youpwe. Hg was not detected in samples collected from Youpwe and Deido. The concentrations of As and Cu in locally dried bonga from Deido market were higher than those from Youpwe ($p<0.05$). The concentrations of Cr was comparable between the two markets.

Table 4. 15: Mean Concentration of trace elements (ug/g dry weight) in locally dried bonga purchased from markets in Deido and Youpwe (n=8)

Locally dried	Dry weight ug/g	Trace element							
Markets	Bonga Purchased	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Deido	Mean	2.7	0.02	1.4	2.1	<DL	0.60	0.38	61.4
Youpwe	Mean	1.6	0.01	1.5	1.2	<DL	0.53	0.29	53.2

4.8 Comparing concentrations between bonga, catfish and shrimp from the Wouri Estuary, Cameroon

4.8.1 Comparing trace elements concentrations between fresh bonga, catfish and shrimp

The concentrations of trace elements varied among the different aquatic species (bonga, catfish and shrimp) from the Wouri Estuary. The highest concentrations of Cr, Zn, Pb, and As were measured in bonga. However, the concentrations of As and Zn in bonga were only slightly higher than those in shrimp. Similar concentrations of Cd were measured in catfish and bonga. The concentrations of Cu differ significantly among the species with the highest concentrations measured in catfish and the lowest in shrimp. Hg concentrations was higher in catfish than shrimp.

Table 4. 16: Mean Concentrations of trace elements in the different aquatic species from the Wouri Estuary, Cameroon.

		Trace element							
Species/Mean concentrations		As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Fresh Shrimp	Mean	1.3	0.006	0.08	5.38	0.01	0.04	0.01	13.9
Fresh Catfish (Muscle)	Mean	0.4	0.12	0.34	18.5	0.37	<DL	<DL	74.4
Fresh Bonga (Muscle)	Mean	2.3	0.11	0.76	10.1	<DL	<DL	<DL	86.5

4.8.2 Comparing trace element concentrations between fresh bonga, catfish, shrimp and locally dried bonga, catfish and shrimp.

The concentrations of As in locally dried shrimp and catfish were higher than those in fresh shrimp and catfish ($p<0.05$). Higher concentrations of Cd were measured in locally dried shrimp than in fresh shrimp. In the contrast, fresh bonga and catfish had higher concentrations of Cd than dried bonga and catfish. The concentrations of Cu, Pb and Zn were higher in the locally dried shrimp than in fresh shrimp. However, Cu and Zn were higher in fresh bonga than in locally dried bonga. Higher concentrations of Cr were measured in locally dried shrimp, bonga, catfish than in fresh shrimp, catfish and bonga. Hg and Ni were higher in locally dried shrimp than in fresh shrimp.

Table 4. 17: Mean concentrations of trace elements (ug/g) in locally dried bonga, catfish, shrimp and fresh bonga, catfish and shrimp.

		Trace element							
	Mean Concentrations	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Deido	Locally dried shrimp	5.3	0.05	0.40	26.5	0.07	0.29	0.18	42.3
	Locally dried catfish	13.4	0.009	2.1	1.5	<DL	<DL	0.11	99.7
	Locally dried Bonga	2.7	0.02	1.4	2.1	<DL	0.60	0.38	61.4
Youpwe	Locally dried shrimp	8.8	0.05	0.91	23.5	0.07	0.46	0.22	53
	Locally dried catfish	0.61	0.022	1.9	1.26	<DL	0.63	0.43	60.1
	Locally dried bonga	1.6	0.01	1.5	3.3	<DL	0.53	0.29	53.2
Wouri Estuary	Fresh shrimp	1.3	0.006	0.08	5.38	0.01	0.04	0.01	13.9
Base Naval	Fresh catfish	0.4	0.12	0.34	18.5	0.37	<Ni	0.08	74.4
Youpwe	Fresh Bonga	2.3	0.11	0.76	10.1	<DL	<DL	0.2	86.5

4.9 Risk Assessment for consumption of fish and shrimp in the Akwa and Makepe Missoke neighbourhood

The estimated intakes of As, Cd, Cu, Hg, Pb and Zn from shrimp and fish were compared to Nutrient Reference values for Australia and New Zealand and the Joint FAO/WHO Expert Committee on Food Additives (JECFA) acceptable intake values.

The estimated intakes (EI) for the trace elements were calculated using the mean concentration of the trace elements in ug/g wet weight and per consumption rate of fish and shrimp based on data from Chapter 2 (average, 95th percentile and maximum consumption). The EI values for the different gender groups (child, women and men) were calculated using the following equation (Culha et al., 2016).

$$EI = \frac{\text{Average concentration of elements ug/g (AC) X Amount of seafood consumed (g)}}{\text{Weight of person (kg) (WP)}}$$

Where EI = Estimated intake of trace element via consumption of shrimp and fish by the different gender groups (in grams)

AC= the concentrations of trace element in shrimp and fish (in ug/g wet weight)

FC= the consumption of fish and shrimp (in grams)

WP= the body weight of the different gender groups (in kg)

The body weights used were 25.7 kg for a Cameroonian child aged 8, 75.4 kg for a woman and 74.8 kg for a man (Kamadjeu et al., 2006). The amounts of locally dried fish and shrimp consumed (average, 95th percentile and maximum consumption) were obtained from the fish consumption survey conducted in the Akwa and Makepe Missoke Neighbourhoods (Chapter 2). The amount of fresh shrimp, bonga, catfish and gill consumed was also obtained from the fish consumption survey (Table 4.20 and 4.21). The daily, weekly and monthly intake of each trace element was calculated using the average, 95th percentile and maximum consumption rates of shrimp, bonga and catfish from the survey. Three scenarios for seafood consumption were evaluated in this assessment. The first scenario considered the maximum exposed individuals, assumed to consume the highest amount of seafood per week. The second scenario of consumption was the 95th percentile and the third scenario was the average consumers. Total arsenic was converted to inorganic arsenic using a conversion rate of 6.88% (Munor et al., 2000). As the liver is not an integral component of the diet of households in the Akwa and Makepe Missoke neighbourhood, it was excluded from the risk assessment.

The Nutrient Reference Values for Australia and New Zealand were used to investigate the level of metal intake considered to be adequate to meet the nutritional needs of people (Table 4.19) (NHMR, 2006).

Table 4. 18: Health based guidance values used for risk assessment in this study

Metals	Values	Reference
Inorganic arsenic	3.0 ug/kg bw/d	JECFA, 2010a
Cadmium	PTMI: 25 ug/kg bw	(JECFA, 2010b)
Lead (child)	9 ug/kg bw/d	JECFA, 2010b
Lead (adult)	3.0 ug/kg bw/d	JECFA, 2010b
Total Mercury	PTWI: 4 ug/kg bw	(JECFA, 2010a)

Table 4. 19: Nutrient Reference Values for Australia and New Zealand

Metals	Children (Age)	Upper level of intake	Men and Women (Age)	Upper level of intake	Source
Copper	1-3yr	mg/day	19+yr	10 mg/day	(NHMRC, 2006)
	4-8yr	mg/day			
	9-13yr	mg/day			
	14-18yr	mg/day			
Zinc	1-3yr	mg/day	19+yr	40 mg/day	NHMRC,2006
	4-8yr	mg/day			
	9-13yr	mg/day			
	14-18yr	mg/day			

Table 4. 20: Amount of fish and shrimp (g) consumed per week by the different gender-cohorts in the Makepe Missoke neighbourhood

Gender	Weight kg	Consumption rate	Locally dried bonga	Locally dried catfish	Locally dried shrimp	Fresh catfish	Gill catfish
Child	25.7	Average	29	387	39	1113	11.4
Woman	75.4						
Man	74.4						
Child	25.7	95th Percentile	85.3	400	57	1500	14
Woman	75.4						
Man	74.4						
Child	25.7	Maximum	2100	3100	652	2500	23
Woman	75.4						
Man	74.4						

Table 4. 21: Amount of fish and shrimp (g) consumed per week by the different gender-cohorts in the Akwa neighbourhood

Gender	Weight kg	Consumption rate	Locally dried bonga	Locally dried catfish	Locally dried shrimp	Fresh bonga	Fresh catfish	Fresh shrimp	Gill bonga
Child	25.7	Average	240	381	95	2083	1813	455	14
Woman	75.4								
Man	74.4								
Child	25.7	95^{th} Percentile	620	750	217	2250	3000	1200	16
Woman	75.4								
Man	74.4								
Child	25.7	Maximum	1167	1138	750	3000	7500	1500	23
Woman	75.4								
Man	74.4								

4.9.1 Risk Assessment for consumption of locally dried fish and shrimp in the Akwa and Makepe Missoke neighbourhoods

4.9.2 Risk Assessment for consumption of locally dried shrimp

The intakes of As, Cd, Cu, Hg, Pb and Zn from shrimp in the Makepe Missoke neighbourhood were below the Joint FAO/WHO Expert Committee on Food Additives (JECFA) and Nutrient Reference values for Australia and New Zealand (Table 4.22). Consequently, the consumption of shrimp by household in the Makepe Missoke neighbourhood was not found to be a pathway of concern for trace elements exposure.

The estimated intakes of As, Cd, Cu, Hg, Pb and Zn in the Akwa Neighbourhood were also below the values set by JECFA and Nutrient Reference values for Australia and New Zealand (Table 4.23). The estimated intakes of As from locally dried shrimp were higher in the Akwa Neighbourhood than in the Makepe Missoke Neighbourhood ($p<0.05$). Intakes of Cd, Cu, Hg and Pb were comparable for both neighbourhoods.

Table 4. 22: Estimated intake of trace elements from locally dried shrimp in the Makepe Missoke neighbourhood

Reference/JECFA Values		InorgAs	Cd	Cu	Hg	Pb	Zn
		3.0 ug/kg/d	25 ug/kg/m	10 mg/d	4 ug/kg/w	3.0 ug/kg/d	40 mg/d
Gender	Consumption rate						
Child	Average	0.12	0.35	0.005	0.013	0.05	0.011
Woman		0.04	0.12	0.002	0.005	0.02	0.004
Man		0.04	0.12	0.002	0.005	0.02	0.004
Child	95th percentile	0.2	0.5	0.007	0.019	0.07	0.02
Woman		0.06	0.17	0.002	0.007	0.02	0.005
Man		0.06	0.18	0.003	0.007	0.02	0.006
Child	Maximum	2.0	5.8	0.08	0.23	0.8	0.2
Woman		0.7	1.9	0.03	0.08	0.3	0.1
Man		0.7	2.0	0.03	0.08	0.3	0.1

Table 4. 23: Estimated intake of trace elements from locally dried shrimp in the Akwa neighbourhood

Reference/JECFA Values		InorgAs	Cd	Cu	Hg	Pb	Zn
		3.0 ug/kg/d	25 ug/kg/m	10 mg/d	4 ug/kg/w	3.0 ug/kg/d	40 mg/d
Gender	Consumption rate						
Child	average	0.29	0.9	0.01	0.23	0.11	0.03
Woman		0.1	0.3	0.004	0.08	0.04	0.009
Man		0.1	0.3	0.004	0.08	0.04	0.009
Child	95th percentile	0.7	1.9	0.03	0.52	0.25	0.06
Woman		0.2	0.7	0.009	0.18	0.08	0.02
Man		0.2	0.7	0.009	0.18	0.09	0.02
Child	Maximum	2.3	6.7	0.09	1.8	0.87	0.21
Woman		0.8	2.3	0.03	0.62	0.29	0.07
Man		0.8	2.3	0.03	0.6	0.30	0.07

4.9.3 Risk Assessment for consumption of locally dried bonga

The intakes of As, Cd, Cu and Zn in the Makepe Missoke neighbourhood were below the recommended values (Table 4.24). Lead (Pb) concentrations were above the upper level of intake for children.

Estimated intake of trace elements (Pb, Cd, As, Zn and Cu) from bonga in the Akwa neighbourhood did not exceed the tolerable weekly intake values established by JECFA and the Nutrient Reference values for Australia and New Zealand (Table 4.25). Mercury (Hg) was below detection limit. Intakes of As, Cd, Cu, Pb and Zn measured in the Makepe Missoke neighbourhood were higher than those in the Akwa neighbourhood.

Table 4. 24: Estimated intake of trace elements from locally dried bonga in the Makepe Missoke neighbourhood

Reference/JECFA Values		InorgAs	Cd	Cu	Pb	Zn
		3.0 ug/kg/d	25 ug/kg/m	10 mg/d	3.0 ug/kg/d	40 mg/d
Gender	Consumption					
Child	Average	0.02	0.06	0.0004	0.05	0.009
Woman		0.008	0.02	0.0001	0.02	0.003
Man		0.008	0.02	0.0002	0.02	0.003
Child	95th percentile	0.07	0.19	0.001	0.15	0.03
Woman		0.02	0.07	0.0004	0.05	0.009
Man		0.02	0.07	0.0004	0.05	0.009
Child	Maximum	1.7	4.9	0.03	**3.9**	0.66
Woman		0.58	1.7	0.01	1.3	0.22
Man		0.59	1.7	0.01	1.4	0.23

Table 4. 25: Estimated intake of trace elements from locally dried bonga in the Akwa neighbourhood

Reference/JECFA Values		InorgAs	Cd	Cu	Pb	Zn
		3.0 ug/kg/d	25 ug/kg/m	10 mg/d	3.0 ug/kg/d	40 mg/d
Gender	Consumption rate					
Child	Average	0.19	0.56	0.004	0.45	0.08
Woman		0.07	0.19	0.001	0.15	0.03
Man		0.07	0.2	0.001	0.15	0.03
Child	95th percentile	0.51	1.4	0.009	1.15	0.19
Woman		0.17	0.5	0.003	0.39	0.07
Man		0.18	0.5	0.003	0.39	0.07
Child	Maximum	0.96	2.7	0.02	2.17	0.37
Woman		0.33	0.93	0.006	0.74	0.13
Man		0.33	0.94	0.006	0.75	0.13

4.9.4 Risk Assessment for consumption of locally dried catfish

The intake of Cd, Cu and Zn from locally dried catfish in the Makepe Missoke neighbourhood were all lower than the permissible levels (Table 4.26). However, the intakes of As and Pb by maximum consumers were above the tolerable intakes (Table 4.26).

The intake values for As, Cd, Cu, Pb and Zn from locally dried catfish in the Akwa neighbourhood were below the permissible levels (Table 4.27). Intakes of As, Pb and Zn in the Makepe Missoke neighbourhood were higher than those in the Akwa neighbourhood. Mercury (Hg) was below detection limit.

Table 4. 26: Estimated intake of trace elements from locally dried catfish in the Makepe Missoke neighbourhood

Reference/JECFA Values		InorgAs	Cd	Cu	Pb	Zn
		3.0 ug/kg/d	25 ug/kg/m	10 mg/d	3.0 ug/kg/d	40 mg/d
Gender	Consumption rate					
Child	Average	1.0	0.03	0.003	0.6	0.17
Woman		0.4	0.01	0.001	0.2	0.06
Man		0.4	0.01	0.001	0.2	0.06
Child	95th percentile	1.1	0.03	0.003	0.6	0.18
Woman		0.4	0.01	0.001	0.2	0.06
Man		0.4	0.01	0.001	0.2	0.06
Child	Maximum	**8.3**	0.27	0.023	**4.7**	1.38
Woman		2.8	0.09	0.008	1.6	0.47
Man		2.9	0.09	0.008	1.6	0.48

Table 4. 27: Estimated intake of trace elements from locally dried catfish in the Akwa neighbourhood

Reference/JECFA Values		InorgAs	Cd	Cu	Pb	Zn
		3.0 ug/kg/d	25 ug/kg/m	10 mg/d	3.0 ug/kg/d	40 mg/d
Gender	Consumption rate					
Child	Average	1.0	0.92	0.003	0.57	0.17
Woman		0.3	0.31	0.001	0.19	0.06
Man		0.4	0.32	0.001	0.19	0.06
Child	95th percentile	2.0	1.80	0.006	1.13	0.33
Woman		0.7	0.62	0.002	0.38	0.11
Man		0.7	0.63	0.002	0.39	0.12
Child	Maximum	2.9	2.7	0.009	1.71	0.51
Woman		1.0	0.94	0.003	0.58	0.17
Man		1.1	0.95	0.003	0.59	0.17

4.9.5 Risk Assessment for locally dried bonga, catfish and shrimp consumption in the Akwa and Makepe Missoke neighbourhood

To assess the overall intakes of trace elements from locally dried bonga, catfish and shrimp by households in the Akwa and Makepe Missoke neighbourhoods, the intake of each element for the different fish species was added. The estimated intakes of Cd, Cu, Hg and Zn from locally dried bonga, catfish and shrimp by the different gender groups in the Makepe Missoke neighbourhood did not exceed the tolerable intake limits. The intakes of As and Pb exceeded the tolerable limits for children. The consumer groups that consumed the maximum amount of locally dried bonga, catfish and shrimp in the Makepe Missoke neighbourhood had intakes of As and Pb which exceeded the maximum allowable values. In the Akwa neighbourhood, Cd, Cu, Hg and Zn were below the tolerable values intakes. Arsenic (As) and Pb exceeded the tolerable intakes in the Akwa neighbourhood. The estimated intakes of As, Pb and Zn in the Makepe Missoke neighbourhood were higher than in the Akwa neighbourhood. Intakes of Cu were similar for both neighbourhoods.

Table 4. 28: Estimated intake of trace elements by different age groups at different concentrations in locally dried fish and shrimp in the Makepe Missoke neighbourhood

Reference/JECFA Values	InorgAs	Cd	Cu	Hg	Pb	Zn
	3.0 ug/kg/d	25 ug/kg/m	10 mg/d	4 ug/kg/w	3.0 ug/kg/d	40 mg/d
74.8 kg male						
Mean	0.4	0.2	0.002	0.005	0.2	0.1
95th percentile	0.5	0.3	0.004	0.007	0.3	0.1
Maximum	**4.2**	3.8	0.05	0.08	**3.2**	0.8
75.4 kg female						
Mean	0.4	0.2	0.003	0.005	0.2	0.1
95th percentile	0.5	0.3	0.004	0.007	0.3	0.1
Maximum	**4.1**	3.8	0.05	0.08	**3.2**	0.8
25.7 kg child						
Mean	1.2	0.5	0.008	0.01	0.7	0.2
95th percentile	1.3	0.7	0.01	0.02	0.8	0.2
Maximum	**12**	11	0.14	0.27	**9.3**	2.2

Table 4. 29: Estimated intake of trace elements by different age groups at different concentrations from locally dried fish and shrimp in the Akwa neighbourhoods

Reference/JECFA Values	InorgAs	Cd	Cu	Hg	Pb	Zn
	3.0 ug/kg/d	25 ug/kg/m	10 mg/d	4 ug/kg/w	3.0 ug/kg/d	40 mg/d
74.8 kg male						
Mean	0.5	0.8	0.006	0.1	0.4	0.1
95th percentile	1.1	1.8	0.01	0.2	0.9	0.2
Maximum	2.2	4.2	0.04	0.6	1.6	0.4
75.4 kg female						
Mean	0.5	0.8	0.006	0.08	0.4	0.1
95th percentile	1.1	1.8	0.01	0.2	0.9	0.2
Maximum	2.2	4.2	0.04	0.6	1.6	0.4
25.7 kg child						
Mean	1.5	2.3	0.02	0.2	1.1	0.3
95th percentile	**3.2**	5.2	0.04	0.5	2.5	0.6
Maximum	**6.4**	12	0.12	1.8	**4.8**	1.1

4.9.6 Risk Assessment for fresh catfish in the Akwa and Makepe Missoke neighbourhood

The intakes of As, Cu and Zn in the Akwa neighbourhood were higher than those in the Makepe Missoke neighbourhood ($p<0.05$). None of the trace elements intakes in both neighbourhoods exceeded the values set by JECFA and Nutrient Reference Values for Australia and New Zealand. Cadmium (Cd), Hg and Pb were below detection limit in fresh catfish. The intakes of As, Cu and Zn from dried catfish were higher than intakes from fresh catfish in both neighbourhoods.

Table 4. 30: Estimated intake of trace elements from fresh catfish in the Makepe Missoke neighbourhood

Reference/JECFA Values		Inorg As	Cu	Zn
		3.0 ug/kg/d	10 mg/d	40 mg/d
Gender	Consumption rate			
Child	Average	0.04	0.0009	0.03
Woman		0.01	0.0003	0.01
Man		0.01	0.0003	0.01
Child	95th percentile	0.05	0.001	0.04
Woman		0.02	0.0004	0.01
Man		0.02	0.0004	0.01
Child	Maximum	0.09	0.002	0.07
Woman		0.03	0.0007	0.02
Man		0.03	0.0007	0.02

Table 4. 31: Estimated intake of trace elements from fresh catfish in the Akwa neighbourhood

Reference/JECFA Values		InorgAs	Cu	Zn
		3.0 ug/kg/d	10 mg/d	40 mg/d
Gender	Consumption rate			
Child	Average	0.06	0.001	0.1
Woman		0.02	0.0005	0.02
Man		0.02	0.0005	0.02
Child	95th percentile	0.1	0.002	0.09
Woman		0.04	0.0008	0.03
Man		0.04	0.0008	0.03
Child	Maximum	0.1	0.006	0.2
Woman		0.09	0.002	0.07
Man		0.09	0.002	0.07

4.9.7 Risk Assessment for gill from catfish and bonga in the Akwa and Makepe Missoke neighbourhood

The Intakes of As, Cd and Zn for gill from bonga in the Akwa neighbourhood were higher than intakes for gill from catfish in the Makepe Missoke neighbourhood ($p<0.05$). The intake of Cu and Pb in the Makepe Missoke neighbourhood were higher than those in the Akwa neighbourhood ($p<0.05$). The estimated intake of As, Cd, Cu, Pb, and Zn in both neighbourhoods did not exceed JECFA Values and Nutrient Reference Values for Australia and New Zealand. Mercury (Hg) was below detection limit.

Table 4. 32: Estimated intake of trace elements for gill from catfish in the Makepe Missoke neighbourhood

Reference/JECFA Values		InorgAs	Cd	Cu	Pb	Zn
		3.0 ug/kg/d	25 ug/kg/m	10 mg/d	3.0 ug/kg/d	40 mg/g
Gender	Consumption rate					
Child	Average	0.0006	0.007	0.00002	0.004	0.0008
Woman		0.0002	0.002	0.000009	0.002	0.0003
Man		0.0002	0.002	0.00001	0.002	0.0003
Child	95th percentile	0.0007	0.009	0.00003	0.005	0.001
Woman		0.0002	0.003	0.00001	0.002	0.0004
Man		0.0002	0.003	0.00001	0.002	0.0004
Child	Maximum	0.001	0.01	0.00005	0.009	0.002
Woman		0.0004	0.005	0.00002	0.003	0.0006
Man		0.0004	0.005	0.00002	0.003	0.0006

Table 4. 33: Estimated intake of trace elements for gill from bonga in the Akwa neighbourhood

Reference/JECFA Values		Inorg As	Cd	Cu	Pb	Zn
		3.0 ug/kg/d	25 ug/kg/m	10 mg/d	3.0 ug/kg/d	40 mg/d
Gender	Consumption rate					
Child	Average	0.002	0.02	0.00002	0.004	0.002
Woman		0.0007	0.005	0.000007	0.001	0.0006
Man		0.0007	0.005	0.000007	0.001	0.0006
Child	95th percentile	0.002	0.05	0.00002	0.005	0.002
Woman		0.0009	0.02	0.000008	0.002	0.0007
Man		0.0009	0.02	0.000008	0.002	0.0007
Child	Maximum	0.003	0.02	0.00003	0.006	0.003
Woman		0.001	0.008	0.00001	0.002	0.0009
Man		0.001	0.009	0.00001	0.002	0.0009

4.9.8 Risk Assessment for fresh shrimp in the Akwa neighbourhood

Estimated intakes of As, Cd, Cu, Hg, Pb, Zn from fresh were below the permissible levels. The intakes of As, Cd, Cu, Hg, Pb, Zn from dried shrimp were higher than from fresh shrimp.

Table 4. 34: Estimated intake of trace elements from fresh shrimp in the Akwa neighbourhood

Reference/JECFA Values		InorgAs	Cd	Cu	Hg	Pb	Zn
		3.0 ug/kg/d	25 ug/kg/m	10 mg/d	4 ug/kg/w	3.0 ug/kg/d	40 ug/kg/d
Gender	Consumption rate						
Child	Average	0.23	0.43	0.01	0.26	0.02	0.03
Woman		0.08	0.14	0.005	0.09	0.009	0.01
Man		0.08	0.14	0.005	0.09	0.009	0.01
Child	95th percentile	0.59	1.14	0.03	0.7	0.07	0.09
Woman		0.20	0.38	0.01	0.2	0.02	0.03
Man		0.20	0.39	0.01	0.2	0.03	0.03
Child	maximum	0.74	1.4	0.04	0.9	0.09	0.11
Woman		0.25	0.49	0.02	0.3	0.03	0.04
Man		0.25	0.49	0.02	0.3	0.03	0.04

4.9.9 Risk Assessment for fresh bonga in the Akwa neighbourhood

The estimated intakes of Cd, As, Zn and Cu from fresh bonga did not exceed the tolerable intake values (Table 4.35). The intakes of Cd, As, Zn and Cu from dried bonga were higher than from fresh bonga.

Table 4. 35: Estimated intake of trace elements from fresh bonga in the Akwa neighbourhood

Reference/JECFA Values		InorgAs	Cd	Cu	Zn
		3.0 ug/kg/d	25 ug/kg/m	10 mg/d	40 mg/d
Gender	Consumption rate				
Child	Average	0.2	0.6	0.004	0.07
Woman		0.1	0.2	0.001	0.02
Man		0.1	0.2	0.001	0.02
Child	95th percentile	0.3	0.7	0.004	0.07
Woman		0.1	0.2	0.001	0.03
Man		0.1	0.2	0.001	0.03
Child	Maximum	0.3	0.9	0.006	0.09
Woman		0.1	0.3	0.002	0.03
Man		0.1	0.3	0.002	0.03

4.9.10 Risk Assessment for fresh bonga, catfish, shrimp and gill consumption in the Akwa Neighbourhood

All the trace element intakes from fresh bonga, catfish, shrimp and gill were added to assess the overall trace element intakes from fresh fish and shrimp in the Akwa neighbourhood. The estimated intakes of As, Cd, Cu, Hg, Pb and Zn were below the Nutrient Reference values for Australia and Zealand and tolerable values set by JECFA.

Table 4. 36: Estimated intake of trace elements from fresh shrimp, catfish, gill and muscle of bonga in the Akwa neighbourhood

Reference/JECFA Values	InorgAs	Cd	Cu	Hg	Pb	Zn
	3.0 ug/kg/d	25 ug/kg/m	10 mg/d	4 ug/kg/w	3.0 ug/kg/d	40 mg/d
74.8 kg male						
Mean	0.1	0.4	0.02	0.1	0.3	0.05
95th percentile	0.3	0.7	0.04	0.2	0.4	0.09
Maximum	0.4	0.8	0.06	0.3	0.7	0.14
75.4 kg female						
Mean	0.2	0.4	0.006	0.1	0.1	0.05
95th percentile	0.3	0.6	0.01	0.2	0.1	0.09
Maximum	0.4	0.8	0.02	0.3	0.2	0.14
25.7 kg child						
Mean	0.5	1.1	0.007	0.3	0.3	0.2
95th percentile	0.9	1.8	0.01	0.7	0.4	0.3
Maximum	1.3	2.4	0.02	0.9	0.7	0.4

4.10 Discussion

4.10.1 Trace elements in sediments from the Wouri Estuary Cameroon

The spatial variability in sediment trace element concentrations in the Wouri Estuary was determined. Results from this study indicate that trace elements are of concern in sediment from the Wouri Estuary. Sediment from the estuary was found to be contaminated with various trace elements (Table 4.2). The highest concentrations of trace elements were for Zn Cr, Cu. These elements were measured in sediment samples collected from freshwater, brackish water and coastal marine area. The high concentrations of Zn, Cr and Cu in sediment samples from the Wouri Estuary could be due to urban runoff and industrial discharge from the city of Douala and municipality of Tiko. Seventy percent of the industries (soap, brewery, food processing, salt, cement, petroleum, textile and metal workshops) in Cameroon are found in the City of Douala. The waste of these industries discharged into the surrounding environment enters the Wouri Estuary directly or indirectly through storm drains, streams and rivers. High concentrations of Cd, Cr, Ni and Zn were measured in surface sediment where the Mungo River discharge (site 6) compared to where the Wouri River (site 4) and Dibamba River (Site 12) discharge. The Mungo River drain a catchment dominated by agricultural, industrial and residential areas, suggesting that this land-use type plays an important role in the contamination of the estuary.

Total As, Cd, Pb and Zn concentrations in sediments for all sites sampled from the Wouri Estuary were below the ANZECC ISQG-L. Cr, Cu and Ni were the only elements that exceeded guideline values low (ISQG-L) but were below guideline values high (ISQG-H) in most sites in the estuary. Mean As, Cd, Cr, Cu, Pb and Zn concentrations in sediment samples from the different types of environment in the estuary were below ISQG-L.

The most enriched elements in the estuary were Cd, Cu and Pb. The Igeo values measured in this study for Cd, Cu and Pb are lower than previously measured in African studies (Table 4.37). Asaah et al., 2006 measured high concentrations of Cd, Cr, Cu, Ni, Pb and Zn in soil samples collected at locations situated in and around mechanical garages, metal workshops and an iron recycling industry in the Bassa industrial zone in the city of Douala. The concentrations of Cd, Cr, Cu, Ni, Pb and Zn measured by Asaah et al., 2006 in soil samples from the Bassa Industrial zone were much higher than the sediment concentrations in this study (Table 4.38). Sediment concentrations measured in this study are higher to concentrations of trace elements in sediment reported in previous studies in Africa (Uwah et al., 2013; Rumisha et al., 2012) but significantly lower than others (Beiras et al., 2003; Ngeve et al., 2015)(Table 4.38). The concentrations of Cd, Pb and Zn measured in study conducted by (Diop et al., 2014) in the Saint Louis Estuary in Senegal were significantly higher than those found in the current study (Table 4.38).

Table 4. 37: Geoaccumulation index values for sediments from the Wouri estuary and other estuaries in Africa

		Trace element							
Estuaries		As	Cd	Cr	Cu	Ni	Pb	Zn	References
Wouri Estuary	Igeo values	0.3	1	0.3	1.1	0.4	0.7	0.09	Current study
Cross River Estuary, Nigeria	Igeo values	-	-	1	-	0.2	0.2	-	(Essien, Antai, & Olajire, 2009)
Eastern Lagoon (Be) Togo		-	2.3	-	-	-	2.2	1.5	(Gnandi, Han, Rezaie-Boroon, Porrachia, & Deheyn, 2011)
Western Lagoon Togo		-	2.8	-	-	-	2.4	1.8	Gnandi et al.,2011

Table 4. 38: Comparison of trace elements concentration (ug/g) in sediments from the Wouri Estuary of Cameroon with other estuaries in Africa and coastal marine areas

	Trace element							
Environment Type	As	Cd	Cr	Cu	Ni	Pb	Zn	References
Wouri Estuary	10	0.1	86	151	27	25	85	Current study
Qua-Iboe River Estuary Nigeria	-	1.1	0.1	0.1	11	0.12	6.9	(Uwah, Dan, Etiuma, & Umoh, 2013)
Saint Louis Estuary Senegal	-	1.3	75	83	10	1308	88	(Diop, Dewaele, Cazier, & Ouddane, 2014)
Soil of Bassa Industrial Zone	7	7.3	422	909	283	3320	3782	(Asaah et al., 2012)
Coast of Cameroon	18	0.2	328	46	457	21	212	(Ngeve, Leermakers, Elskens, & Kochzius, 2015)
Galacia, NW Iberian Peninsula	88		365	2097	60	1108	5589	(Beiras, Bellas, Fernandez, Lorenzo, & Cobelo-Garcia, 2003)
Dar es Salaam coast, Tanzania	1	0.04	9.6	2.1	2.9	2.2	9.3	(Rumisha, Elskens, Leermakers, & Kochzius, 2012)
Guandu Watershed Rio de Janaeiro, Brazil	47	6.9	123	234	22	238	248	(Ferreira, 2015)

Large spatial variations were found in the concentrations of As, Cd, Cr, Cu, Ni, Pb and Zn in the estuary. The concentrations of these elements at sites closer to the city of Douala were slightly higher, and decreased further as sampling locations were further away from the city. However, high concentrations of As, Cd, Cr, Cu, Ni, Pb and Zn were observed at some sampling sites further away from the city. This indicates that there are different anthropogenic pressures from various sources on the estuarine system. These anthropogenic pressures (such as agricultural runoff, discharges from non- point sources, discharges of water and waste from fishing and marine vessels) may have contributed to the variability of trace element concentrations in the estuary. The variation observed in the estuary suggest that strong tidal influences and freshwater influxes may also have contributed to the distribution of these elements in surface sediments. The results for Hg were below detection limit in all sediment samples. Other studies have reported higher trace element concentrations closer to urban areas. Ferreira (2015) reported high concentrations of As, Cd, Cu, Cr, Ni, Pb and Zn closer to urban areas in the state of Rio de Janeiro, Brazil. The concentrations of As, Cd, Cu, Cr, Ni, Pb and Zn measured by Ferreira (2015) were much higher than the sediment concentrations in the current study.

The ability of sediments to accumulate trace elements depends on its physicochemical characteristics, therefore different sediments will reach different concentrations from identical dissolved sources of trace element (Bryan & Langston, 1992). The particle size of sediment and organic carbon content can lead to increased trace element concentrations. Sediments with particles of high surface area will accumulate more trace elements than particles of low surface area, and sediments high in organic carbon content will bind more trace elements than those with low organic carbon (Rainbow, 2006). Therefore muds (high organic content, small particle size) accumulate more trace elements than sands (low organic content and large particle size). Differences in the iron oxide contents of aquatic sediments can also lead to increased trace elements concentration. Trace elements such as Ag, As, Cu and Pb can be incorporated into the sediment as a result of oxides and hydroxides of iron (Bryan & Langston, 1992).

The concentrations of Cr, Ni, Pb and Zn were correlated with % OM. Organic matter has been widely recognised as a significant sink of contaminants (Laura, Andrade, Elena, Raul, & Jorge, 2003). It can influence the concentrations of contaminants in estuarine sediment. The highest organic matter (OM) was measured in freshwater environment closer to people/urban areas. The high OM loadings in the freshwater environment suggest that this part of the estuary receives the highest organic matter discharged from domestic waste, dead animals and plants from the Douala metropolitan area. Most sites in brackish water and marine/brackish water had similar patterns of OM, with the exception of site 15 with the lowest OM. Higher concentrations of Cd, Cr, Pb, Zn, As, Cu and Ni were observed at these sites with increased OM. The lowest concentration of these elements were observed at site 15 with decreased OM. The organic matter (OM) at all sites was above 1%. These results are higher than the percentage of OM reported by Essien et al., 2009 in the Cross River Estuary in Nigeria but significantly lower than those reported by Diop et al., 2015 in the Saint Louis Estuary in Senegal.

The HCl leach results indicate that a significant amount of As, Cd, Cr, Cu, Ni, Pb and Zn is bioavailable for uptake by aquatic organisms. The most bioavailable elements were Cd, Cu, Pb and Zn. The bioavailable fractions measured in this study for Cd, Cu, Pb and Zn are higher than those previously measured by Diop et al., 2015 in the Louis Estuary in Senegal and Madejon et al., 2008 in the Domingo Rubio Estuary in Spain. However, the bioavailable fraction measured by Madejon et al., 2008 for As was much higher than those measured in this study.

Table 4. 39: Bioavailable trace metals concentrations in surface sediment from the Wouri estuary and other estuaries in Senegal

		Trace element							
Estuaries		As	Cd	Cr	Cu	Ni	Pb	Zn	References
Wouri Estuary	Mean values	6	0.07	40	276	15	20	68	Current study
	% bioavailable	-	95	41	108	58	76	83	
Saint Louis Estuary	Mean values	-	0.03	1.6	1.4	0.37	0.6	2	(Diop, Dewaele, Cazier, Diouf, & Ouddane, 2015)
	% bioavailable	-	9	3	6	14	2	23	
Dakar Coast	Mean values	-	0.04	2.8	1.9	1.3	0.5	1.5	(Diop et al., 2014)
	% bioavailable	-	21	5	15	42	17	22	
Domingo Rubio Estuary, SW Spain	Mean values	38	0.5	0.5	-	-	-	-	(Madejon, Burgos, Murillo, Cabrera, & Madejon, 2009)

4.10.2 Trace elements in NZ shrimp, bonga, catfish and shrimp from the Wouri Estuary

Trace elements that are elevated or enriched in the sediment were also high in shrimp and fish. The most bioavailable trace elements (Cu and Zn) as measured by the leach were the elements most elevated in the estuary organisms. The species with the highest concentrations of As and Cu was shrimp. Higher concentrations of Zn was measured in bonga. Pb was not detected in the fresh fish but was an element of concern for the risk assessment. There were no differences in the concentrations of As, Cr, Ni, Hg, Pb and Zn between the NZ oven dried shrimp and the NZ freeze dried shrimp. However, the concentrations of Cd and Cu in the oven dried shrimp and freeze dried shrimp were significantly different ($p<0.05$)

4.10.3 Trace elements in shrimp from the Wouri Estuary

Trace elements (As, Cd, Cr, Cu, Hg, Ni, Pb and Zn) were measured in the fresh shrimp samples collected from the Wouri Estuary and locally dried shrimp purchased from different markets in the city of Douala. All shrimp samples analysed contained trace elements above the detection limits. These results were lower than concentrations of trace element in shrimp reported in some previous studies conducted in Turkey, Sri Lanka and South China (Table 4.40) (Yilmaz and Yilmaz, 2007; Senadheera and Pathiratne, 2005; and Ip et al., 2005).

High concentrations of As, Cd, Cr, Cu, Ni, Pb and Zn were found in sediment compared to shrimp. There was no relationship between sediment and shrimp. Shrimp are migratory species and it may be inappropriate to use a small number of shrimp for this relationship (Kikkert, Crowl, & Covich, 2009). Direct up-take from water was the unique process involved in trace elements accumulation in shrimp. High concentrations of Cu was measured in shrimp collected from site 14. The high concentrations of Cu found in shrimp collected from site 14 could be due to urban runoff and industrial discharge in the Bassa industrial zone.

Table 4. 40: Comparing the concentration of trace elements (ug/g wet weight) in shrimp, bonga and catfish from the Wouri Estuary to other studies from various locations around the world

	Trace element								
Location	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn	References
Wouri Estuary shrimp	1	0.006	0.08	5	0.02	0.04	0.011	13.9	Current study
Wouri Estuary Bonga	0.3	0.002	0.05	0.33	-	-	-	5.9	Current study
Wouri Estuary Catfish	0.09	-	0.08	0.14	-	-	-	5.1	Current study
Iskenderun Bay, Turkey	-	-	13.1	42	-	1.6	0.3	10.3	(A. B. Yilmaz & Yilmaz, 2007)
Sri Lanka North Western P.	-	0.07	0.28	-	-	-	0.25	-	(Senadheera & Pathiratne, 2005)
Pearl River Estuary, S. China	-	0.84	0.2	28	-	0.56	0.14	15.8	(Ip, Li, Zhang, Wong, & Zhang, 2005)

4.10.4 Trace elements in catfish from the Wouri Estuary

The concentrations of Cr found in the gill of catfish *(Arius heudelotii Valenciennes, 1840)* from the Wouri Estuary were lower than those from the Ondo State Coastal Waters in Nigeria (Table 4.41). The concentrations of Zn measured in the muscle and gill of this study were significantly higher than those found in the study by Olusola and Festus (2015). Kantati et al., 2013 measured higher concentrations of Cu in the gill of *Sarotherodon melanotheron* compared to this study. High concentrations of Cu were found in the liver of catfish from the Wouri Estuary than those found in the liver of *Sarotherodon melanotheron* from the Be Lagoon (Lome) in Togo.

Different organs of catfish from the Wouri Estuary accumulate different concentrations of trace elements. The highest concentrations of Zn, Cu and As were measured in the liver. However, the primary site of trace element uptake from water are the gill, especially if the trace elements are bound to particulate matter (Klavins, Potapovics, & Rodinov, 2009). The high concentrations of trace element (Zn, Cu and As) found in the liver may be because the liver is a metabolically active tissue with metal-binding proteins (Ploetz, Fitts, & Rice, 2007).

The species with the highest concentrations of Pb and Cd was catfish. This study found that the liver of catfish concentrated trace elements to a greater extent than the muscles and gill. The concentrations of As, Cu, Zn and Cd were generally higher in the liver of catfish than in the muscles and gill. However, higher concentration of Cr was measured in the gill of catfish than in the liver and muscles. While there was no difference in the concentrations of Cr in the liver and gill, there was a significant difference in the concentration of Zn in liver, gill and muscle ($p < 0.05$).

Higher concentrations of As, Cr, Cu and Zn were found in the locally dried catfish purchased from Deido than those from Youpwe. However, the concentrations of Pb in the locally dried catfish from Youpwe was higher than those from Deido. The concentrations of As, Cr, Cu and Zn were much higher in the locally dried catfish than in the fresh catfish. Trace elements (Cd, Cu and Pb) were found at higher concentrations in the fresh catfish than in the fresh bonga. Catfish are sediment dwelling aquatic species. The high concentrations of Cd, Cu and Pb in the fresh catfish may be due to its direct contact with sediment.

Table 4. 41: Mean concentrations of trace element (ug/g dry weight) in catfish (Arius heudelotii Valenciennes) from the Wouri Estuary compared to other studies in Africa

Current study fresh catfish				Ondo State Coastal Waters Nigeria			Be Lagoon (Lome) Togo			
Arius heudelotii Valenciennes, 1840				*Arius Latisculatus*			*Sarotherodon melanotheron*			
Metals	Muscle	Liver	Gill	Metals	Muscle	Gill	Metals	Muscle	Liver	Gill
Cr	0.08	0.13	0.13	Cr	BDL	0.63	Ni	0.34	6.23	0.5
Cd	<DL	0.12	0.004	Cd	0.31	0.52	Cu	0.40	2.4	4.6
Pb	<DL	0.013	0.07	Pb	0.05	0.08	-	-	-	-
Zn	5.1	56	13.2	Zn	0.51	0.59	-	-	-	-
Cu	0.14	17.9	0.46	Ni	0.01	0.04	-	-	-	-
				(Olusola & Festus, 2015)			(Kantati, Kodjo, Gnandi, Ketoh, & Gbeassor, 2013)			

4.10.5 Trace elements in bonga from the Wouri Estuary

Trace elements were detectable in all the organs of fresh bonga and the locally dried bonga analysed. The different organs of bonga (liver, gill and muscle) accumulated different concentrations of trace element. The liver was observed to accumulate higher concentrations of trace elements (As, Cd, Cr, Cu, Pb and Zn) than the gill and the muscle. The relatively higher levels of trace metals accumulated in the liver may be due to its accumulation potential.

Trace elements (As, Cd, Cr, Cu and Zn) were found at higher concentrations in the locally dried bonga, catfish and shrimp than in the muscle of the fresh bonga, catfish and shrimp. Personal observations of the methods used by the local commercial fish driers in fishing communities in the Wouri Estuary showed that the fresh fish and shrimp were not adequately cleaned and properly handled before smoke-drying. In addition, the dried fish and shrimp on display in the markets were exposed to contaminants from other sources. The poor handling practices of the locally dried bonga, catfish and shrimp in the markets and during drying could be the cause of the higher concentrations of trace elements measured in the locally dried bonga, catfish and shrimp than in the fresh bonga, catfish and shrimp. The scales being the outer structures of a fish are in continuous and direct contact with the pollutants present in water and the surrounding environment (Brraich & Jangu, 2012). The tiny scales which were present on the locally dried bonga and were not removed before smoke-drying could also be accounted for the relatively high trace element concentrations in those samples.

The concentrations of Zn measured in the liver of *A. Maculatus* and *L. Saliens* by Pradit et al., 2009 and Fernandes et al., 2007 were much higher than those measured in the current study (Table 4. 42). Okoye (1994) reported trace element concentrations in dried fish from Nigerian markets. The concentrations of Cu and Cr measured in the locally dried bonga from Deido and Youpwe markets in the city of Douala were similar to those found in dried fish from Nigerian markets (Table 4.43). However, higher concentrations of Pb and Cd were recorded in dried fish in the study conducted by Okoye (1994) than in this study. Higher concentrations of Zn were observed in the locally dried bonga purchased from Deido and Youpwe markets than those in dried fish from Nigerian markets.

Table 4. 42: Trace elements (ug/g) in fresh bonga from the Wouri Estuary, Cameroon and those of fish in Iskenderun Bay, Paramos Lagoon and Songkhla Lake

	Current study			Iskenderun Bay Turkey		Paramos Lagoon Portugal		Songkhla Lake Southern Thailand	
	Ethmalosa fimbriata			*Solea/Lascaris*		*L. Saliens*		*A. Maculatus*	
Metals	Muscle	Liver	Gill	Muscle	Liver	Muscle	Liver	Muscle	Liver
As	0.3	1.6	0.4	1.74	1.98	-	-	0.54	0.41
Cd	0.002	0.106	0.007	0.04	0.39	-	-	0.02	0.17
Cr	0.05	0.62	0.10	0.70	1.64	-	-	-	-
Cu	0.33	9.5	0.27	5.64	22.9	2.64	262	0.98	44.2
Ni	BDL	BDL	BDL	1.01	1.55	-	-	5.4	0.5
Pb	BDL	0.15	0.05	0.39	2.98	-	-	0.19	0.24
Zn	5.9	58.2	22.4	27.5	32	25.7	88.6	20.9	784
				(A. B. Yilmaz, Sangun, Yaglioglu, & Turan, 2010)		(Fernandes, fernandes-Fontainhas, Cabral, & Salgado, 2007)		(Pradit, Wattayakorn, Angsupanich, Baeyens, & Leemakers, 2009)	

Table 4. 43: Trace metals in locally dried bonga from Deido and Youpwe markets compared to dried fish from Nigerian markets

	Current study		(Okoye, 1994)
Metals	Deido Market	Youpwe Market	Nigerian Markets
Cd	0.017	0.012	0.45
Cr	1.42	1.47	1.48
Cu	2.05	3.3	2.59
Pb	0.376	0.288	8.99
Zn	61.42	53.2	35.8

There was significant differences in the concentrations of trace element in the samples analysed for fresh shrimp, bonga, catfish and locally dried shrimp, bonga and catfish. Contaminants from other sources and atmospheric deposition which are trace elements enriched may have increased the concentrations of trace element in the locally dried samples as the locally dried samples exposed to these contaminants had higher tissue concentrations of trace element than the fresh samples from the estuary.

4.10.6 Risk Assessment

A key objective of this study was to undertake a health risk assessment for the consumption of shrimp and fish sourced from the Wouri Estuary. This assessment indicates that Pb and As are of concern for fish consumers consuming locally dried fish and shrimp in the Akwa and Makepe Missoke neighbourhoods. Other studies from various locations around the world have reported intake of trace elements through consumption of seafood (Yap et al., 2015 and Han et al., 1998). However, this assessment is the first to be done in the Akwa and Makepe Missoke neighbourhoods and the first to assess the health risk for the consumption of shrimp and fish sourced from the Wouri Estuary.

Households in the Akwa and Makepe Missoke neighbourhoods were found to have elevated intakes of Pb and As through the consumption of dried bonga, catfish and shrimp. More than 60% of the households interviewed in these neighbourhoods consumed bonga, catfish and shrimp. The estimated intake of trace elements from consumption of bonga and catfish were greater than from shrimp. This suggests that individuals consuming fish might be at greater risk than those who consume shrimp. However, the risk may be higher for people who consume all three seafood (bonga, catfish and shrimp). Lead (Pb) and As intakes are elevated even though concentrations in the environment were not elevated (Chapter 4).

Consumption of dried and fresh seafood in the Akwa and Makepe Missoke neighbourhoods differs among households. Households in the Makepe Missoke neighbourhood are exposed to more As, Cd, Pb and Zn from locally dried shrimp, bonga and catfish than households in the Akwa neighbourhood. When looking at individual species, higher intakes of Cd from locally dried shrimp were measured in the Akwa neighbourhood than in the Makepe Missoke neighbourhood. The estimated intakes of As, Cd, Cu, Pb and Zn from locally dried bonga and catfish in the Makepe Missoke neighbourhood were higher than those in the Akwa neighbourhood. In the contrast, the intakes of As, Cu and Zn from fresh catfish in the Akwa neighbourhood were higher than in the Makepe Missoke neighbourhood. This study found that the intakes of As, Cd, Cu, Hg, Pb and Zn from dried shrimp and fish were higher than from fresh shrimp and fish. The method of preparation is important.

Arsenic (As) and Pb intakes in the current study are much greater than reported for previous studies (Table 4. 44). These increased intakes may be due to higher seafood consumption. Falco et al., 2006 reported elevated intakes of As and Pb due to higher seafood consumption in Spain. The estimated intakes of As reported by Falco et al., 2006 were much higher than those in the current study. However, intakes for Pb in this study were higher than those reported by Falco et al., 2006. The estimated intakes of As, Cd, Cu, Hg, Pb and Zn from fish and shrimp in the Akwa and Makepe Missoke neighbourhoods were compared to intakes from other studies around the world (Table 4.44)

Table 4. 44: Estimated intake of trace elements from fish and shrimp from other studies compared to current study.

			Estimated intake of trace elements					
Other studies and current study			As	Cd	Cu	Hg	Pb	Zn
Akwa Current study	Maximum	Child	6.4	12	0.12	1.8	4.8	1.1
		Adult	2.2	4.2	0.04	0.6	1.6	0.4
Makepe Current study	Maximum	Child	12	11	0.14	0.27	9.3	2.2
		Adult	4.1	3.8	0.05	0.08	3.2	0.8
(Alipour, Pourkhabbaz, & Hassanpour, 2015), Iran		-	0.0006	0.0005	0.0004	-	0.001	0.002
(Petkovsek, Grudnik, & Pokorny, 2012), Slovenia		-	0.018	0.02	-	0.07	0.015	-
(Culha, Yabanli, Baki, & Yozukmaz, 2016), Turkey		Child	0.06	-	0.03	0.004	0.02	-
		Adult	0.04	-	0.02	0.003	0.01	-
(Han et al., 1998), Taiwan	Maximum	Shrimp	0.015	0.017	5.59	0.315	-	13.2
		Fish	0.102	0.029	1.07	1.70	-	26.7
		Adult	-	0.291	0.49	-	-	5.43
(Falco, Llobet, Bocio, & Domingo, 2006), Spain			217.7	1.34	-	-	2.48	-

5. Overall conclusions and recommendations

5.1 Conclusions

This study has illustrated that sediment in the Wouri Estuary has accumulated trace elements. The concentrations of trace element found in this study were comparable to those of other studies in Africa and other countries. The variability of trace element concentrations indicates that the estuary is subjected to contaminants from diverse sources. The entire estuary showed evidence of human influence although very low concentrations of trace element were observed in some areas. Sediment in most of the different types of environment in the estuary exceeded ISQG-L guideline values for Cr, Cu and Ni. As more than 40% of these elements are bioavailable to biota, the risk to aquatic organisms is elevated.

Trace elements were found to accumulate in shrimp, bonga and catfish from the Wouri Estuary, with the exception of Hg and Ni which were not detected in some of the samples. Shrimp, bonga and catfish accumulate significant concentrations of trace element.

Households consuming locally dried shrimp and fish in the Akwa and Makepe Missoke neighbourhoods were found to have elevated intakes of Pb and As. Maximum consumers of these seafood are at greater risk.

5.2 Study limitations

The Wouri Estuary covers a surface area of 1800km^2 (Gabche and Smith, 2002). This research involved collection of 19 sediment samples from different locations in the estuary. However, several point and non-point pollution sources are present in the greater area of the Wouri Estuary. This indicates that other locations in the estuary may be contaminated by trace elements. In order to fully understand the level of trace elements contamination in the estuary more sampling sites are required.

A relatively small number of biota samples were collected from a limited number of locations in the estuary, commercial fishing markets along the estuary and markets in the city of Douala. A larger number of samples from the different locations is required to fully understand the level of trace elements contamination in shrimp and fish from the Wouri Estuary.

5.3 Recommendations

Based on the survey results, it is recommended that

Similar surveys are carried out regularly at least once every four years, using the data collected from the present survey as a reference to monitor changes in the perceptions of consumers and habits towards shrimp and fish consumption.

Catch data on artisanal fisheries in the Wouri Estuary were not available. Given present-day fishing activities in the estuary, it is vital to determine the amount of shrimp and fish caught from the estuary. Therefore research needs to be conducted to determine current catch and supply to the local markets.

In order to gain a clearer picture of the consumption of shrimp, bonga and catfish across the city, a similar survey should be carried out in other neighbourhoods in the city of Douala to collect data for other specific ethnic groups suspected to be high consumers of seafood.

The results from this study indicate that there is the need for further research to investigate whether salinity has affected the bioavailability of As, Cr and Ni in the different types of environment in the estuary. Further research is also required to investigate whether other aquatic organisms in the estuary are affected as trace elements also have the ability to cause adverse effects to a wide range of organisms.

More sediment sampling is recommended in the estuary for an in depth assessment of trace elements accumulation. The sampling area should have multiple locations and large number of sediment samples should be collected (>10) per sampling site.

An ecological risk assessment is recommended in future to investigate whether seabirds (e.g. fish eagle and the kingfisher) that feed on fish are exposed to trace elements and to what degree they are exposed. Trace elements have also been found in sediments from the Wouri Estuary. Therefore, research is required to assess the impact of these elements on aquatic organisms (e.g mangrove crabs) in the estuary that dwell in sediment.

This study illustrated that aquatic organisms (shrimp, bonga and catfish) in the Wouri Estuary have accumulated trace elements. The study involved collection of a relatively small number of fresh shrimp samples from a limited number of locations in the estuary, and also small number of fresh bonga, catfish and locally dried bonga, catfish, shrimp from different markets in the city of Douala.

Shrimp and fish are an important source of protein in the diet of both rural and urban households of Cameroon. Therefore, it is recommended that shrimp and fish from the Wouri Estuary be monitored regularly for trace elements.

This study indicates elevated intakes of As and Pb by seafood consumers in the Akwa and Makepe Missoke neighbourhoods. It is recommended that trace element concentrations in fish and shrimp from the Wouri Estuary should be monitored regularly to prevent excessive build-up of these elements in the human food chain. Further investigation is recommended in the future for other aquatic organisms and fish species from the estuary consumed by households in the Akwa and Makepe Missoke neighbourhood. This will safeguard the health of consumers. Reduced consumption of locally dried bonga, catfish and shrimp from the Wouri Estuary is also recommended to reduce the intake of these elements.

The elevated Pb and As in dried seafood may be due to the poor handling practices in the markets by market vendors and the methods used by the local commercial fish driers in the fishing communities for smoke-drying. However, these seafood are from different locations in the Wouri Estuary which could be enriched with Pb and As. Further research is required to investigate whether the high concentrations of trace element in the locally dried shrimp, bonga and catfish is as a result of contaminants from other sources including atmospheric deposition which are known to be trace element enriched.

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7. Appendices

Appendix 1

A 1.1 Survey Questionnaire

Survey Questionnaire design and implementation

Name of interviewer: __________________________

Date: ____________________________ Day of week: __________________________

Time started: _________________________ Time Ended: _____________________________

Site: ____

Location of resident (Region/Division/Sub-Division/Quarter/Street)____________________

Sex of person being interviewed: M F

1. How many people do you have in your household?
Number: __________________
2. How many adult are there?
Number: ___________________
3. Do any of the adult eat shrimp?
Yes___ No____ If yes, number: ________________________
4. How many children are there?
Number: ______________________
5. Do any of the children eat shrimp?
Yes___ No_____ if yes, number: _________________________
6. What is the number or weight of shrimp your household consumes?
(i) per day________________ (ii) per week__________________ (iii) per month________
7. How is it usually prepared?

____
8. How often do you eat shrimp that you bought from the market?
(i) Daily (ii) Weekly (iii) Monthly (iv) Yearly
9. How important to your family meals are the shrimp. Are they:
(i) Not important (ii) somewhat important (iii) important (iv) very important
10. What are your top three reasons for eating shrimp? (Select and rank up to three responses)
(i) i caught it (ii) it taste good (iii) it's quick to fix (iv) it's easy to fix (v) it's healthy (vi) it's inexpensive (vii) it's readily available (viii) my family likes it
11. Do any of the children eat bonga/catfish?
Yes___ No_____ if yes, number: ______________________

12. What is the number or weight of fish (bonga/catfish) does your household consume?
(i) Per day_______________ (ii) per week_________________ (iii) per month________

13. How is it usually prepared?

____

14. How often do you eat bonga/catfish that you bought from the market?
(i) Daily (ii) Weekly (iii) Monthly (iv) Yearly

15. What parts are usually consumed for each meals?
(i) tissue (ii) liver (iii) head (iv) bones (v) gills

16. How important to your family meals are the bonga/catfish. Are they:
(i) not important (ii) somewhat important (iii) important (iv) very important

17. What is your reason for eating bonga/catfish?
(i) i caught it (ii) it taste good (iii) it's quick to fix (iv) it's easy to fix (v) it's healthy (vi) it's inexpensive (vii) it's readily available (viii) my family likes it

A 1.2 Translated questionnaire in french

I- IDENTIFICATION

Nom d'interviewer: ____
Date: ______________________ Jour de la semaine: ______________________
Heure de début: ______________________ Heure de fin: ______________________
Site: ____
Localité de résident ou habitant: ____
(région/département/arrondissement/quartier/rue)
Sexe: Male ☐ Female ☐

II- Question relie à la consommation de crevette dans le quartier d'Akwa DOUALA.

1- Combien des personnes sont-il dans votre maison?

Nombre: ______________________________

2- Combien des adultes?

Nombre: ______________________________

3- Il y a t-il certaines adultes qui consomme les crevettes?

Oui ☐ Non ☐ si oui nombre

4- Combien des enfants sont dans votre maison?

Nombre: ______________________________

5- Il y a t-il les enfants qui consomme les crevettes?

Oui ☐ Non ☐ Si oui nombre: ______________________________

6- Quelle quantité des crevettes est consumée?

☐ ☐ ☐

Par jour Par semaine Par mois

7- Les crevettes sont préparer commet?

8- Quelle est la fréquence de la consommation des crevettes que vous achetez au marcher au cours de l'année?

Journalier Hebdomadaire Mensuellement Annuellement

9- Quelles parties sont consumées d'habitude pendant le repas?

Tissue Foie Tète Les os Branchies
Le crevette entier

10- Quelle importance donnera-t-il de votre famille pour la consommation de ce produit?

Aucune importance Peur d'importance important
Très importa

11- Donner trios raisons majeur pour la consommation de crevette.

J'ai pêché Ca un bon gout C'est facile à nettoyer
c'est rapide ang c'est s c C'est toujo ccessi
C'est salutaire Ma famille aime ca

Appendix 2

Table A 2.1 Concentration of trace elements (ug/g dry weight) in fresh shrimp collected from the Wouri Estuary, Cameroon

Dry weight	Trace element							
Sites	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Bwape (4)	3.9	0.04	0.8	24.6	0.08	0.28	0.09	70.7
Koo (5)	7.1	0.02	0.3	22.3	0.07	0.19	0.03	69.5
Kombo (6)	5.6	0.04	0.3	28.8	0.08	0.08	0.01	73.2
Bouma (7)	2.1	0.01	0.2	11.2	0.03	0.11	0.04	45.6
Moungongue (8)	6.5	0.02	0.1	27.6	0.07	0.09	0.01	72
Wengue (9)	3.8	0.02	0.9	9.5	0.05	0.42	0.15	54.2
Acre (10)	2.6	0.02	0.2	7.4	0.04	0.19	0.07	61.4
K. Moukoko (11)	5.2	0.04	0.3	39	0.06	0.20	0.04	72.7
Missipi (12)	5.4	0.03	0.3	33.9	0.08	0.13	0.05	69.1
Dongo (13)	7.3	0.03	0.4	36.6	0.06	0.23	0.07	71.2
Manoka (14)	8.6	0.05	0.2	46.5	0.1	0.17	0.03	80.9
Entrée Epassi (15)	11.2	0.04	0.3	26.4	0.08	0.16	0.03	75.8
Epassi (16)	4.6	0.02	0.1	20.5	0.07	0.06	0.02	58.6
S. Ganaberi (17)	5.2	0.02	0.6	25.2	0.05	0.19	0.05	69.9
Entrée Mbiako (18)	11.3	0.04	0.3	29.6	0.07	0.24	0.04	74.8
Mbeguerekume (19	9	0.03	0.6	24.6	0.07	0.21	0.06	64.3

Table A 2.2 Concentration of trace elements (ug/g) in fresh shrimp from New Zealand

	Trace element							
	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Oven Dried Shrimp	3.5	0.099	0.82	78.4	0.03	0.45	0.22	58.2
	2.6	0.077	0.79	69.6	0.04	0.56	0.27	55.5
	2.9	0.096	1.96	73.1	0.03	1.04	0.19	52.9
	2.7	0.114	0.41	65.7	0.03	0.33	0.09	56.1
	1.9	0.099	0.53	59.6	0.02	0.35	0.11	44.5
	2.6	0.095	0.61	70.2	0.03	0.49	0.18	52.8
	2.9	0.071	0.39	65.1	0.04	0.37	0.09	51.2
Freeze Dried Shrimp	2.6	0.119	0.63	72.2	0.03	0.42	0.19	55.1
	2.2	0.107	0.48	70.5	0.02	0.28	0.19	50.6
	2.8	0.118	0.70	89.1	0.06	0.49	0.24	65.7
	2.1	0.320	0.26	82.9	0.03	0.19	0.05	56.5
	2.8	0.155	0.53	61.8	0.02	0.53	0.21	60.6
	2.9	0.126	1.74	75.6	0.03	0.49	0.16	59.9
	2.7	0.138	0.43	72.5	0.04	0.56	0.18	58.5

Table A 2.3 Mean Concentration of trace elements (ug/g dry weight) in fresh catfish purchased from fishing market along the Wouri Estuary (Base Naval)

	Dry weight ug/g	Trace element							
Parts	Fresh Catfish	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Muscles	Mean	0.4	<DL	0.38	0.65	<DL	<DL	<DL	23.98
Gills	Mean	0.6	0.02	0.65	2.27	<DL	<DL	0.32	64.64
Liver	Mean	0.4	0.28	0.28	39.6	0.83	<DL	0.86	123.8

Table A 2.4 Mean Concentration of trace elements (ug/g dry weight) in fresh bonga purchased from fishing market along the Wouri Estuary (Base Naval)

	Dry weight	Trace element							
Parts	Bonga	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Muscles	Mean	1.4	0.01	0.24	1.54	<DL	<DL	<DL	27.6
Gills	Mean	2.2	0.04	0.58	1.68	<DL	<DL	0.31	136.7
Liver	Mean	1.8	0.12	0.67	10.3	<DL	<DL	0.17	63.3

Table A 2.5 Trace elements in soil samples of the Bassa Industrial Zone in the city of Douala

The concentrations of trace element in soil samples from the Bassa Industrial Zone in the city of Douala followed the order Zn>Pb>Cu>Cr>Ni>As>Cd.

Trace element concentrations in soil samples (ug/g) of the Bassa Industrial Zone in the city of Douala

Element	Concentrations	Mean concentrations
As	0-63.7	8.9
Cd	0-7.3	1.3
Cr	27.8-422.7	89
Cu	12.1-909	96.8
Ni	9-283.7	43.4
Pb	0-3320	302
Zn	24-3782	421.4

Table A 2.6 Correlations between trace elements in sediment and shrimp

As, Cd, Cr, Cu, Ni, Pb and Zn in sediment and shrimp were not correlated.

Correlations between sediment and shrimp from the Wouri Estuary, Cameroon

	As	Cd	Cr	Cu	Ni	Pb	Zn
As	-0.31	1					
Cd	0.15	-0.19	1				
Cr	-0.02	0.19	0.26	1			
Cu	-0.01	-0.19	-0.28	0.065	1		
Ni	-0.23	0.08	0.27	0.062	0.33	1	
Pb	-0.11	0.064	0.065	0.16	0.19	0.14	1
Zn	-0.25	-0.04	0.07	-0.03	0.24	0.20	-0.03

Appendix 3. Photos.

Figure A 3.1 Fresh shrimp samples from the Wouri Estuary, Cameroon

Figure A 3.2 locally dried shrimp from markets in the city of Douala

Figure A 3.3 locally dried shrimp from markets in the city of Douala

Figure A 3.4 Fresh Bonga from the Wouri Estuary, Cameroon

Figure A 3.5 locally dried bonga from markets in the city of Douala

Figure A 3.6 Fresh catfish from the Wouri Estuary

A 3.7 Locally dried catfish from markets in the city of Douala

A 3.8 Large open market in Douala

A 3.9 River Wouri outskirts of the city of Douala

A 3.10 Aerial view of the city of Douala

A 3.11 One of Douala's neighbourhood, slightly different perspective